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SUPERSONIC TRANSPORT LUBRICATION SYSTEM INVESTIGATION

by

W. L. Rhoads

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RESEARCH LABORATORY  
**SKF INDUSTRIES, INC.**  
ENGINEERING AND RESEARCH CENTER  
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FIRST PERIODICAL REPORT  
ON  
SUPERSONIC TRANSPORT LUBRICATION SYSTEM INVESTIGATION  
PHASE II

by

W. L. Rhoads

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

May 22, 1968

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## SUPERSONIC TRANSPORT LUBRICATION SYSTEM INVESTIGATION

by

W. L. RhoadsABSTRACT

Ball bearings and bellows face seals for use on Mach 3 aircraft turbine engine mainshafts have been tested in screening tests using jet lubrication and inert gas blanketing. Bearing operating temperatures up to 700°F have been explored under typical engine load and speed conditions with the seals exposed to 1200°F air and to a pressure differential of 100 psi.

Of the three lubricants evaluated, Mobil Jet II ester (MIL-L-23699 specification) permitted thermal system instabilities resulting in bearing failures at temperatures in excess of 550°F. Mobil XRM 154D silicone oil, was found to have adequate lubricating properties but exhibited the tendency to form thermal decomposition products even in an inert atmosphere which appears to render it unsuitable for long-term operation. Mobil XRM-109F synthetic hydrocarbon with Kendex high molecular weight mineral-oil base resin additive was found suitable for operation to 700°F and will be run in longer-term tests. No bearing-originated difficulties of operation were observed with either XRM-109F or XRM 154D lubricants. Progress has been made in improving seal design and materials to provide more trouble-free operation, but the bellows test seals continue to be the most critical components in the system.



SUPERSONIC TRANSPORT LUBRICATION SYSTEM INVESTIGATION

by

W. L. Rhoads

I. INTRODUCTION

This is the first periodical report under NASA Contract NAS3-6267, Phase II and covers Task I (procurement and set-up of equipment) and Task II (screening tests) of Phase II of the contract.

The performance of aircraft gas turbine mainshaft ball bearings, seals, and lubricants under simulated (Mach 3) supersonic transport engine conditions is being studied using the most advanced materials, designs, and manufacturing techniques available. An inert gas blanketed recirculating system with jet lubrication was used for all testing. Three candidate lubricants were evaluated. The results of these tests as well as those conducted in the previous Phase I are being used to select lubricants and test conditions for extended running.

II. SUMMARY AND CONCLUSIONS

Within Task I, all test bearing procurement was completed. Test seal procurement has progressed but is not yet complete. During Task II, screening tests of three hours duration at specified defined test conditions have been run with three lubricants. These lubricants are Mobil Jet II, an ester meeting the MIL-L-23699 specification; Mobil XRM 154D, a silicone oil; and Mobil XRM-109F, a synthetic hydrocarbon with the addition of 10% by weight of Kendex resin (highly refined mineral oil). All tests were made using split inner ring ball bearings of WB49 steel as test bearings which were made to SKF Industries' 459980H design. A variety of seal bellows, carbon, and shoulder materials were used as test seals in seal designs developed by the Koppers Company.

The test series performed in this Task show the following:

1. Mobil Jet II ester is apparently satisfactory for use up to about 550°F bearing outer race temperature. At high temperatures thermal instabilities of the system arise with this fluid resulting in bearing failures. This fluid will be used in the 50 hour base-

line test, to be run at 500°F, planned for Task III of this contract.

Indications are that thermal instabilities such as were exhibited at temperatures above 550°F with this oil are caused by a change in heat transfer properties of the fluid, perhaps by a change in surface wetting characteristics.

2. Mobil XRM 154D silicone while providing adequate lubrication at 650°F, exhibited decomposition products even in the presence of less than 0.02% oxygen in the chamber atmosphere and is considered unsuitable for long-term operation. In addition, severe oil seal wear was observed with the fluid. It is not clear however, that this wear is necessarily attributable to the lubricant.

3. Mobil XRM-109F synthetic hydrocarbon with an addition of 10% Kendex mineral oil base resin is suitable for at least short term use at temperatures to 700°F and will be tested for a longer period at 650°F.

4. Oil seals remain the most failure prone test element in the test system used; however, by the proper selection of oil seal carbon, shoulder plating, face load, and oil cooling of the oil shoulder, it has been possible to get sustained leakage rates of on the order of 1 scfm without periodic lift-off for periods of up to 30 hours. This offers hope for longer trouble-free operation in future tests.

### III. DETAILS

#### 1. Background

In gas turbine engines designed for use in future generations of supersonic transport aircraft, the mainshaft thrust bearings and the seals used to contain the lubricant in the bearing chamber must be capable of operating at 600°F and above. Since lubricant degradation must be minimized for long term operation at these high temperatures, nitrogen blanketing may be employed to reduce oxygen to a very low level in the bearing and lubricant system.

The current state of development of bearings, seals, and lubricants is such that the operation under the conditions specified for advanced supersonic transport engines is definitely possible, but that extended operation of candidate bearing-seal-lubricant systems, now in progress in the present study and elsewhere is needed to establish temperature limitations and reliabilities.

Within this contract, the **SKF** Industries Research Laboratory has completed Phase I in which an inerted bearing-seal-lubricant system was used to test several lubricants under simulated supersonic jet engine conditions. The results of Phase I testing are summarized in (1)\*. In Phase I the most promising lubricant found was Mobil XRM 177F, which consists of the XRM 109F base-oil used in the present Phase II and a proprietary boundary lubricating additive of the organic-phosphate class.

#### 2. Research Objectives

It is the purpose of Phase II of the program to perform additional investigations of the operational limits of the best currently available ball bearing, seals, and additional lubricants in an inerted high temperature recirculating lubrication system under conditions simulating those expected in the main propulsion power units of an advanced Mach 3 supersonic transport aircraft. It is expected that this extended research will result in:

- a) Data pertaining to the maximum temperature capabilities, up to 700°F outer race bearing temperature, of several promising lubricants not previously tested in a nitrogen blanketed recirculating lubrication system

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\*Numbers in parenthesis refer to references at the end of the text.

- b) Operating experience with a modified bearing design (Series II) with new cage material and silver plating process.
- c) Additional data on the behavior of bellows face seals and performance of piston ring secondary face seals at extreme speed, temperature, and pressure differentials.
- d) Longer-term performance (50 to 250 hours) data on bearing-seal-recirculating lubrication systems under simulated supersonic transport engine conditions with several of the most promising fluids found under Phase I and Task II, Phase II testing.

Of the above objectives the Tasks I and II so far completed, has covered items a, b and most of c, but not the tests of piston ring seals under c, and none of the long-term performance tests of d.

The next Tasks of this program, already in progress, will cover the operation of several fluids, including an ester run without inert gas blanketing, for periods of up to 50 hours. The final Task will cover two endurance tests of up to 250 hours each using the most promising fluids found up to that time.

The phasing of effort is shown in the Gantt Chart in Enclosure 1 which is current as of May 27, 1968. Appendix I contains a definition of the scope of the present effort.

### 3. Test Elements

A general schematic drawing of the test apparatus used in this program is shown in Enclosure 2. An assembly drawing of the recirculating test rig is included as Enclosure 3. Detailed descriptions of the apparatus and its' capabilities are given in (1, 2, 3, 4). This apparatus was used in testing in Phase I of the contract and satisfies all requirements defined in Appendix I.

a. Test Bearings

All bearings and cages specified in Appendix I are on hand and meet the specifications set forth in that Appendix. The test bearings used in all screening tests in this Task II were 459980H (Series II) design having CVM WB49 steel rings and balls. This steel has hot hardness properties suitable for rolling bearing use to 1000°F. Enclosure 4 shows this bearing design. Series II design bearings, discussed in detail in (3) have modified geometry (higher conformity at the outer race and lower conformity at the inner race) compared to Series I bearings used throughout Phase I of the project and are intended to reduce heat generation by reducing spin at the inner ball-race contacts. Comparison of heat generation data between Series I and Series II designs using the same fluid are available but have not yet been fully analyzed and will therefore be presented in the Second Periodical Report. It does appear however, from a preliminary review of these data that the expected reduction in heat generation has materialized. One of the purposes of these tests is to evaluate the relative adherence properties of ion deposited silver and electro-plated silver on steel cages. Electroplated cages were tested in Phase I of the contract. In the first test in this Task II an ion silver plated M1 steel cage identical in design to those utilized in Phase I tests (459980/W40) was used. In all subsequent tests ion silver plated 4340 steel cages (459980FS1) were used. Enclosure 5 shows the design of these cages.

Six 459980H bearings, one M1 steel cage, and five 4340 steel cages were expended in testing reported herein.

b. Test Seals

The dual test seal arrangement shown in Enclosure 3 has been used in all testing to date. This arrangement consists of an oil bellows face seal (with a 105 psi pressure drop across it) and an air bellows face seal (5 psi pressure drop across it). The number of bellows seals specified in Appendix I are available. Requirements for materials are consistently being re-evaluated with the sub-contractor and cognizant NASA personnel in order to provide the best possible bellows seals. In addition, two seals having a piston-ring secondary sealing arrangement (instead of bellows) are on order and will be evaluated in a later test of this Phase.

Several variations of materials have been used in both the air and oil seal locations. The particular variations utilized in each test are specified in Enclosure 6. The basic oil seal design is shown in Enclosure 7, the basic oil seal shoulder is shown in Enclosure 8, and the basic air seal and shoulder are shown in Enclosure 9. Both seals have alloy or steel bellows and the carbon face is machined with a dam so located that the bellows is essentially pressure balanced. Carbon pads or lands are provided (inboard of the sealing dam on the oil seals and both inboard and outboard of the sealing dam on the air seal) to distribute the bellows spring face load and residual gas pressure unbalance over a large contact area. The carbon contacts the shoulder, made of steel and plated with wear resistant material, which rotates with the shaft. Tested seals requiring the replacement of carbon rings or replating of the shoulder are reworked by Koppers Company on a subcontract basis. The lapping of both carbon and shoulder surfaces when necessary is being done by Laboratory personnel using lap plates and techniques supplied by Koppers.

In testing to date, the primary problem area has been the oil seal, probably because of the large pressure drop across it compounded by the relatively high rubbing velocity between the carbon and shoulder. If enough seating force is provided to insure that lift-offs with resulting high leakages do not occur, high carbon or shoulder wear results. Progress has been made in controlling this wear by utilizing (wear resistant but somewhat abrasive) CDJ83 carbon against chromium-carbide instead of chromium plated shoulders. Although this gives good results (leakage on the order of 1-2 scfm for up to 30 hours in long-term tests to be reported in subsequent Periodical Reports), the plating still wears, leading to failure. Additional shoulders are being plated with tungsten-carbide and aluminum-oxide, both harder than chromium or chromium-carbide, in an attempt to gain increased trouble-free operating time.

The air seal, even though hotter than the oil seal and having the same rubbing velocity, has proven to be essentially trouble-free, most likely because of the small pressure drop across it.

#### c. Lubricants

Temperature viscosity data for the three lubricants evaluated in screening tests in this Task II are presented in Enclosure 9. These oils are:

- (1) Mobil Jet II - an ester-base formulation meeting the MIL-L-23699 specification. This oil is a second generation of a type of oil previously supplied to MIL-L-7808 specifications. In its present formulation more stable base stock components have been used which were not previously available.
- (2) Mobil XRM-154D - a modified silicone oil which according to the supplier has had long chain alkyl groups added to its structure either in addition to or in place of the normal methyl or phenyl groups which one finds in the siloxane structure in the current silicone oils.
- (3) Mobil XRM-109F plus 10% (by weight) of Kendex 0839 Resin - XRM 109F is a hydrocarbon material synthesized by the polymerization of a fairly pure mono-olefin so that it can be considered a single chemical species composed of molecules of a chain length distribution depending on the type, method and degree of polymerization. It has a reasonably good resistance to thermal degradation and is susceptible to additive improvement. The Kendall Resin is a very high molecular weight residual (4500CS) of a Pennsylvania crude oil which has been subjected to a rigid super refining process, the details of which are proprietary. In bench scale experiments it has shown properties of an additive to enhance the lubricating qualities of other hydrocarbon oils and in this project will be used to test the possibility of replacing conventional synthetic anti-wear additives.

#### IV. TEST RESULTS

Screening tests run with the three selected fluids are reported by type of lubricant. Actually the second test with Mobil XRM-154D was run after the test with Mobil XRM-109F plus Kendex resin additive as can be seen by the Gantt Chart of Enclosure 1. This delay was necessitated by the required analysis of heavy decomposition products formed during the first Mobil XRM-154D test. As also can be seen from the Gantt Chart several other tests (a qualifying and a partial baseline-endurance test) were

conducted between some of the screening tests. These results, which include promising long-term seal tests of up to 30 hours, have been reported in the monthly progress reports but are not part of Task II and therefore will be summarized in subsequent periodical and final reports. Appendix II presents condensed data sheets for all screening runs in Task II. Enclosure 11 presents a summary of these test results as well as all screening tests run in this rig in Phase I of the contract. Enclosure 12 summarizes acid number and viscosity data for the lubricants used and Enclosure 6 presents a tabulation of the various test elements used in each test.

Test conditions for these screening tests are detailed under Task II in Appendix I. Deviations from these conditions are explained in the following text.

#### 1. Mobil Jet II Ester Oil Tests

##### a) 550°F Test

This test was run for 2.2 hours at an outer ring temperature of 540°F, an inner ring temperature of 560 to 570°F, and an oil inlet temperature of 450°F. Test termination was caused by oil seal lift-off and loss of the oil charge. During the early part of the test, oil seal leakage was approximately 3 scfm which increased to 10 scfm at test termination. There were several minor oil seal lift-offs during this time and one lift-off near the end of the test which caused the bearing cavity pressure to momentarily increase to 15 to 20 psi. Air seal leakage was approximately 10 scfm throughout the test. Bearing temperature remained steady throughout the run.

Upon disassembly it was found that the test bearing cage had seized on the outer ring lands (to prevent this, all subsequent tests were run with the cage to outer ring land clearance increased to 0.030"). There was moderate cage pocket wear. There were (silver) debris on all parts of the bearing; however, the ball tracks appeared in reasonably good condition. There was no evidence of oil coking on any of the bearing cavity parts. The oil seal and shoulder were found to be scored while the air seal and shoulder appeared in good condition except for evidence of heavy contact on the outboard pads. No measurable wear was observed on either seal carbon. The oil seal carbon was found to be coned toward the bore (about 0.0005" from sealing dam OD



to the bore) while the shoulder was flat, except for the area outboard of the sealing dam contact area which was found to be coned upward from the face by less than 0.0001".

It was thought that the cage seizure was due to loss of oil. Based on the absence of thermal instabilities during the run and the reasonably good condition of the ball paths, the lubricant was considered suitable for further testing. Photographs of test elements are presented in Enclosures 13 and 14.

b) 600° - 700°F Test

Two runs were made in this test. The first was conducted for a total of one hour and was terminated due to high oil seal leakage before full test conditions were reached. During start-up, a total seal leakage of 7.8 scfm was observed at 4,000 rpm shaft speed of which 7 scfm was across the oil seal. This low air-seal leakage compared to the first test is attributed to the relapping of the carbon face and the use of another shoulder ring. By the time 11,000 rpm was reached the leakage had decreased to 2.5 scfm (total). Shortly after reaching 14,000 rpm (outer ring temperature 570°F) the temperature of the inner and outer rings suddenly increased although no torque increase was noted. The rig was immediately shut down to prevent bearing failure. The rig was restarted after some cool down, and after running 8 minutes the oil seal began to leak excessively (on the order of 15 scfm) and oil was pumped out the vent system. The rig was shut down (before loss of oil flow to the test elements) and it was noted that statically the oil seal was leaking on the order of 15 scfm.

After disassembly the test bearing was found to be in serviceable condition with slight cage wiping in the outer ring lands and rather heavy cage pocket wear. There was evidence of a ball track on the unloaded half of the inner ring although no surface distress was seen. The oil seal and shoulder were in poor condition with the seal carbon completely worn down and the shoulder face badly scored. The air seal and shoulder appeared in good condition. Enclosures 15 and 16 present photographs of these test elements.

Since this was not considered a valid test of the oil, a second test was run for a total of 1.4 hours of which 0.2 hours were at 600°F test conditions. Run termination was caused by test bearing seizure. Oil seal leakage was consistently around

1 scfm while air seal leakage varied between 3 and 4 scfm. At outer ring temperatures above about 540°F the bearing appeared thermally unstable (as evidenced by several inner ring temperature excursions) and required considerable manipulation of "I" housing heater power (0 to 2 KW), shaft cooling (0 to 40 scfm), and oil flow (0.8 to 2 gpm) to control both the rise of inner and outer ring temperatures as well as the differential between the two rings which varied between 10 and 50°F, the inner ring being hotter, except during excursions when the inner ring became up to 90°F hotter.

Upon disassembly it was found that the test bearing was badly smeared (extruded ring material in evidence) on both halves of the inner ring as well as the outer ring. The "unloaded" half of the inner ring was found to have a radial crack, considered to be due to the sudden seizure. The cage rails had wiped the outer ring, as would be expected under the circumstances, and heavy ball wear was found. No evidence of coking was seen on anything except the test bearing, which was coked. The oil seal appeared in rather good condition with some evidence of "chatter" on the shoulder presumably due to the increased face load and had worn about 0.001". The air seal likewise appeared in reasonably good condition, with some evidence of "chatter" on the shoulder and had worn about 0.001". Photographs of test elements are shown in Enclosures 17 and 18.

Based on the results of this and previous tests, it is concluded that the maximum short-term bearing temperature for this lubricant in the test rig employed is 550°F (450°F oil inlet). The higher (500°F) oil inlet temperature employed in the last two runs appears to have a detrimental effect upon performance as instabilities in bearing temperature were observed at temperatures between 540° and 600°F while the first test (450°F oil inlet) ran smoothly for 2.2 hrs. at 540-550°F bearing outer ring temperature.

It was found in testing under Phase I of this program (1) that there were two general types of lubrication-related bearing failures; those related to an insufficient lubricant film thickness and those related to thermal instabilities. Thermal instability failures are caused by the inability of the lubricating system to limit temperature excursions of the test bearing, which result in loss of internal clearances and sudden seizure as was observed with the Jet II fluid. These failures are

believed to be due to peculiar heat transfer properties of the lubricant-bearing combination and can probably be influenced by bearing geometry and method of oil delivery as well as by lubricant surface-wetting characteristics.

## 2. Mobil XRM-154D Silicone Oil Tests

Two tests were run with this fluid. The first, an attempted 550°F run, ran a total of 2.3 hours with a 45 minute shutdown after 1.2 hours to replace a malfunctioning slip ring. Outerring temperature did not get above 490°F (1.2 hours between 470° and 490°F) despite about 5 kw of "I" housing heating, full test speed, varying oil flow between (approximately) 3/4 and 3 gpm, heating the housing to over 600°F, and using 460°F oil inlet temperature (instead of 450°F). Some shaft cooling was required throughout the test. Test termination was caused by an outer ring temperature excursion and subsequent rig lock-up after shut down. During the test the oil seal leakage was constant around 1 scfm except at the end of the test (seemingly corresponding to the temperature excursion) when a lift-off occurred with a resulting sudden increase in bearing chamber pressure (above 25 psi) which blew the oil charge out of the venting system. Visual observation of the oil flow meter during the shutdown showed that oil was being delivered to the test components. After the rig was shutdown, the oil seal appeared to be held open with leakage on the order of 6-8 scfm. Air seal leakage was between 2 and 4 scfm.

Upon disassembly it was found that heavy oil deposits, some "gummy", some dry white powder, were on all parts of the rig exposed to the oil. It is assumed that these deposits were building up during the test, even though some deposits were no doubt due to "cooking" of the oil remaining in the rig after oil loss. It is probable that they contributed to both the oil seal lift-off by bellows deposits, and to the bearing thermal excursion by disturbing heat transfer. A high oxygen content of 1% vs. specified 0.5% maximum was observed in the bearing chamber at one point in the test. A high oxygen content was also observed in the interseal cavity. This oxygen leakage was later traced to leaking thermocouple plugs in the shaft and to several small scratches on the shaft stack-up parts which allowed the air in the shaft, (approximately 100 psi higher pressure than the bearing cavity) to enter the

bearing cavity. This problem has been remedied and low oxygen contents were observed in all subsequent tests.

Both air and oil seal carbons were in reasonably good condition with negligible wear within the accuracy of the measuring method. The oil shoulder showed some evidence of "chatter", although not as much as in the last several runs. The test bearing had heavy oil deposits. After cleaning, evidence of thermal take-up of internal clearance (running on the unloaded half of the inner ring) was found. Moderate surface distress was found in both ball tracks, the cage pockets were heavily worn, and evidence of contact between the cage O.D. and the bearing outer ring noted. Photographs of test elements are shown in Enclosures 19 and 20. Enclosure 21 presents photographs of other rig parts. All Enclosures show the heavy decomposition products.

Portions of the deposits were examined by both NASA and Mobil personnel and it was determined that they were caused by the level of oxygen present during the test. It was decided to run another test, tentatively three hours at 600°F and three hours at 700°F with 500°F inlet oil temperature. It was found, however, that it was not possible to run at 600°F, possibly because of different surface films and heat transfer properties in a lower oxygen environment. To keep the test bearing temperature as low as possible, the oil inlet temperature was reduced to 480°-495°F, the bearing housing to 500° to 520°F, and the inner ring temperature held 10° to 30°F cooler than the outer ring. In this way it was possible to operate the outer ring at 630° to 650°F. Test duration was 3 hours at these conditions.

During the first half hour at test conditions two shut-downs occurred because of shear pin breakage. The exact cause is not known and the problem was solved by using heavier shear pins for the remainder of this test only. The remaining 2.5 hours ran without incident.

The total seal leakage was 1.4 to 1.7 scfm with the majority going through the oil seal for the first 2 hours and splitting evenly in the final hour. Action was then taken to increase outer ring temperature to 700°F. Immediately, the oil seal lifted-off and the bearing cavity pressure increased to 20 to 25 psi. The test was allowed to run for 15 minutes in this condition during which time 2 gallons of oil were added to the sump to make up for lost oil. When the seal did not reseal, the rig was stopped.

Upon disassembly, the test bearing was found to be in very good condition. The air seal and shoulder were in good condition with negligible carbon wear. The oil seal shoulder was heavily worn, with up to 0.005" deep grooves at the location of carbon contact. The carbon had worn a negligible amount. It was noted that the oil seal shoulder ran 50° to 100°F hotter than it did during another test run at the same temperature using Mobil XRM-109F plus 10% Kendex resin. This may indicate that the silicone fluid is a poorer heat transfer medium or that its heat generation or deposit forming characteristics are different in the rubbing seal interface.

Although oxygen content during this test was 0.009 to 0.02% some oil deposits were still visible in the bearing housing after test which indicates that this fluid seems to provide adequate lubrication but decomposes at the test temperature and produces deposits on rig elements which are considered unacceptable for long-term operation. Therefore, no further testing will be undertaken with this oil.

Enclosures 22 and 23 present photographs of the test elements from this run.

3. Mobil XRM-109F plus 10% (by weight) Kendex 0839  
Resin Additive

One test was run with this fluid. It was originally scheduled to be run for 3 hours at a bearing outer ring temperature of 550°F with 450°F oil inlet temperature. If no failure occurred, the test was to be run for an additional 3 hours at a bearing outer-ring temperature of 600°F with 500°F oil inlet temperature. It was found, however, that with the Kendex additive, it was not possible to run at a bearing outer-ring temperature below approximately 620°F with 450°F oil inlet temperature. It was accordingly decided that the rig would be run at as low a temperature as was practical for 3 hours and then a 3 hour test at 700°F would be attempted.

By lowering the oil inlet temperature to 430°F, the rig housing to 420°F (instead of 550°F, and by using shaft cooling to cause the inner ring to run 10 to 15°F cooler than the outer instead of at least 10°F hotter as specified, it was possible to run the first three hours at outer ring temperature between 580°F and 620°F. Of this approximately 2 hours ran at

around 580°F. Oil flow did not have any appreciable effect on temperature so it was held around 1.5 gpm. Because of possible temperature differential problems causing distortion in the rig, it was considered inadvisable to try and run cooler. During this test the total seal leakage stabilized at between 0.3 and 0.4 scfm. Because of the very low leakage it was impossible to determine the leakage path.





Housing and oil heating were then increased and up to 3 kw of heat was applied to the shaft and "I" housing. A bearing outer-ring temperature of 690°F was obtained within an hour. Approximately 0.4 hours after reaching 700°F test conditions the oil seal lifted off and did not seat for the remaining 2.6 hours of the run. Seal leakage through the oil seal ranged from 5 to 10 scfm during this time. This continual high leakage caused the outer ring temperature to fluctuate between 670°F and 710°F. The test was terminated when the time-up life was reached.

Upon disassembly the test bearing was found to have very slight glazing in the ball paths and light cage pocket wear. The air seal carbon had worn approximately 0.007" and there was evidence of some carbon build-up on the shoulder and possibly some slight shoulder wear in the carbon tracks. The oil seal carbon had worn approximately 0.010" and had worn a groove about 0.002" deep in the chromium plate of the shoulder. (The chromium at the bottom of these grooves appeared greyish, and indication of localized overheating.)

Oil was blown out of the system shortly after the test was completed because of seal lift-off and could not be circulated in the normal manner during cool down. Therefore, a considerable amount of coking was formed on test elements. This prevents any direct comparison between coking of XRM-177F oil and the XRM-109F oil plus Kendex.

This fluid is considered satisfactory for longer-term tests at 650°F. Enclosures 24 and 25 present photographs of test elements from this run.

REFERENCES

1. Rhoads, W.L. and Sibley, L.B., "Supersonic Transport Lubrication System Investigation", Final Report on Phase I of NASA Contract NAS3-6267, NASA CR-54662,  Report AL67T060, (1967).
2. Hingley, C.G., et al, "Supersonic Transport Lubrication System Investigation", Semiannual Report No. 1, NASA CR-54311,  AL65T038, (1965).
3. Hingley, C.G., and Sibley, L.B., "Supersonic Transport Lubrication System Investigation", Semiannual Report No. 2 NASA CR-54312,  AL65T077 (1965).
4. Rhoads, W.L., and Sibley, L.B., "Supersonic Transport Lubrication System Investigation", Semiannual Report No. 3, NASA CR-54313,  AL66T032 (1966).





1864-000-5122

Contract NAS3-6267 Progress Report Period 6/23/67 through 5/2/68

Title SST Lubrication System Investigation

Contractor **SKF** Industries, Inc.

Prepared by G. Chiacarini Date May 22, 1968

G. Chiacarini  
Chiccarini

NASA

# CONTRACT PROGRESS SCHEDULE

AL68T046

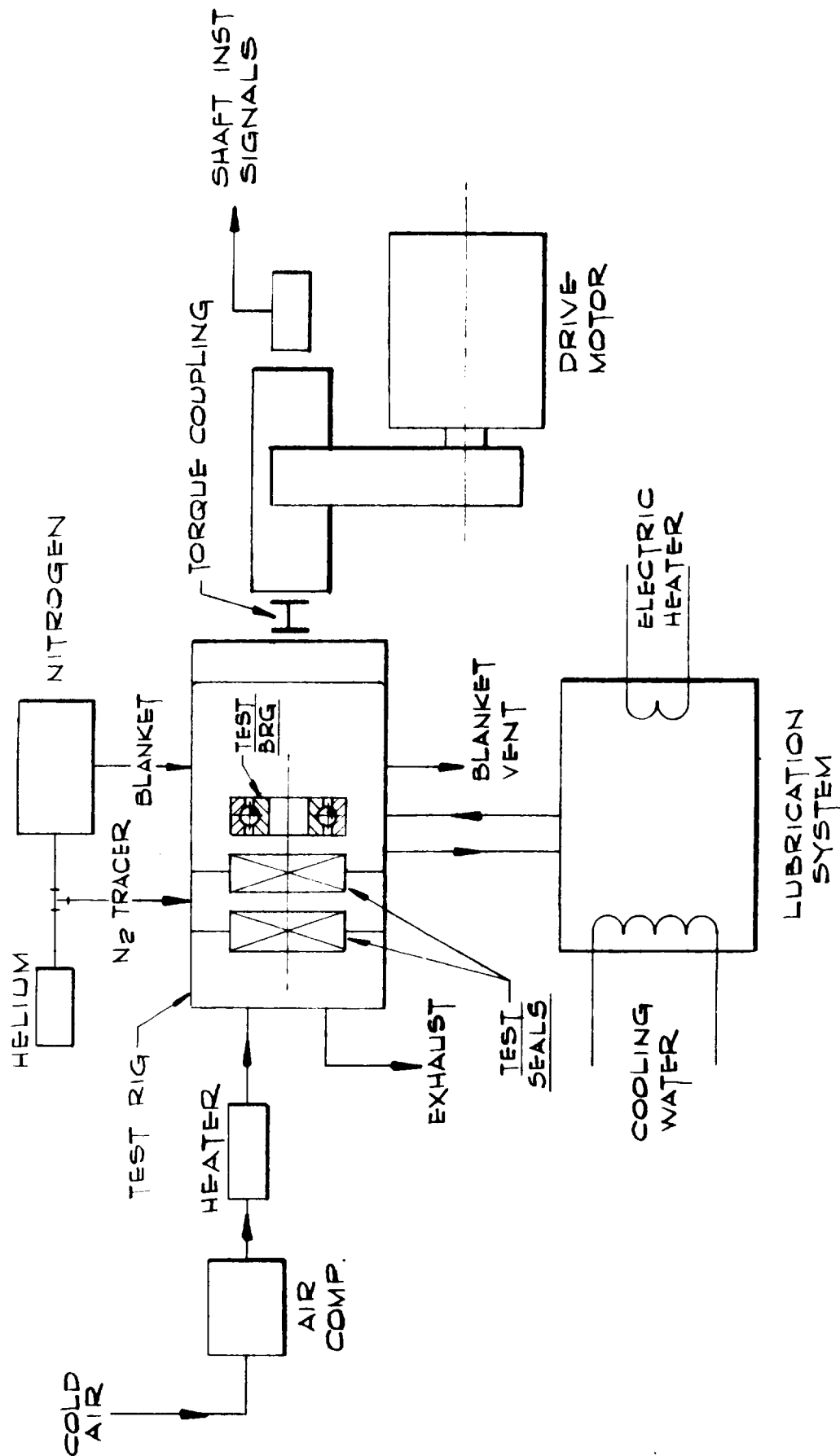
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	1967												1968																
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TASK I Rig & Test Bearings Seals & Fluid Selection																									(20)				
Bearing Procurement																									10	100	10.0		
Seal Procurement																									10	50	5.0		
Task II Screening Tests																									(25)				
First Fluid (Mobil Jet II)																									9	100	9.0		
Second Fluid (Mobil XRM-154D)																									8	100	8.0		
Third Fluid (Mobil XRM-109F plus 10% by weight Kendall Resin)																									8	100	8.0		
Submission of Draft of First Periodical Report (Task I & II)																									0				
Approval of First Periodical Report																									1				
Distribution of First Periodical Report																									1				
TASK III Baseline Tests																									5	50	2.5		
Qualifying Tests #1																									5	100	5.0		

(1) Rescheduled as described in Monthly Progress Report No. 5

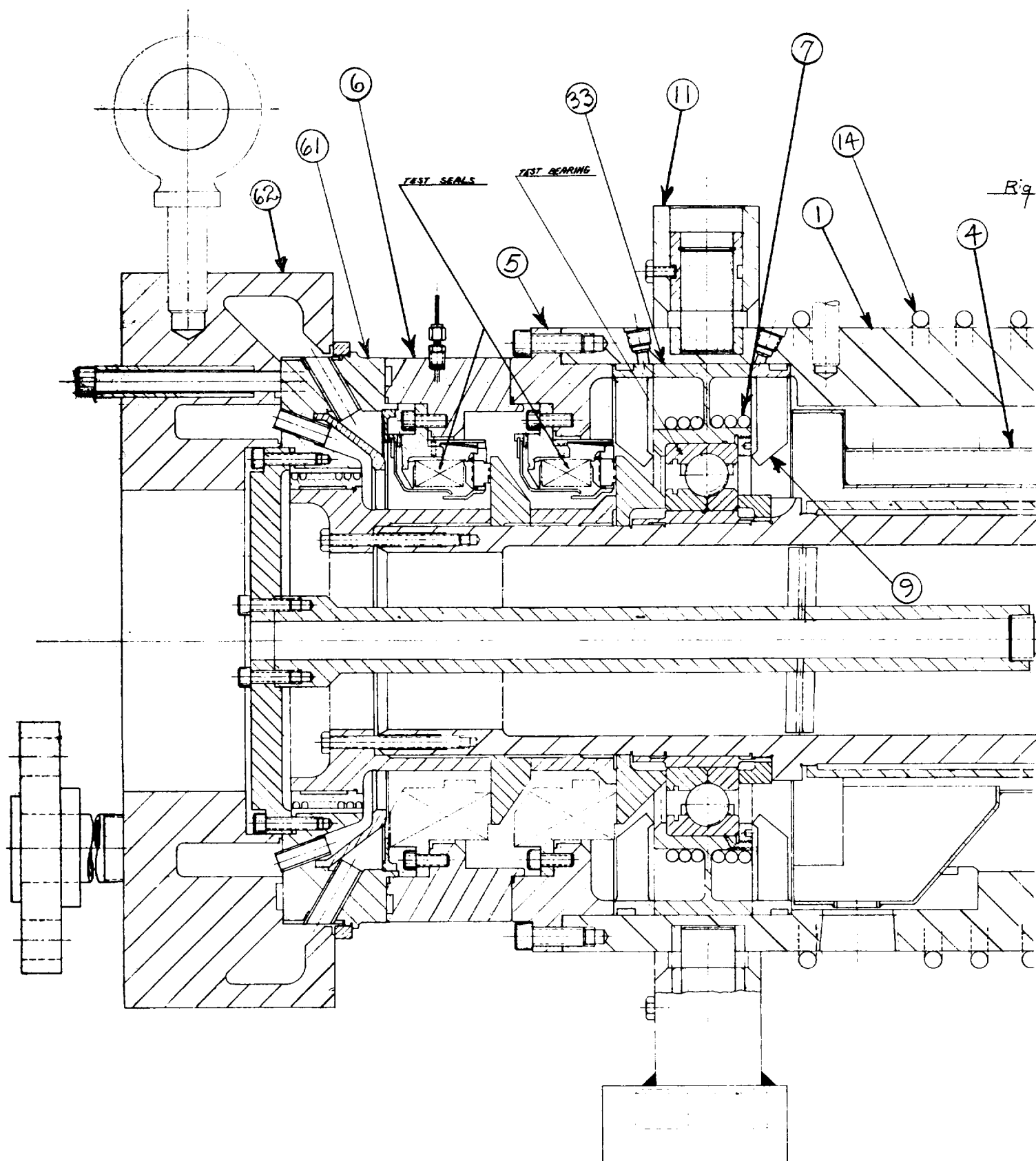
### CONTRACT PROGRESS SCHEDULE

Contract NAS3-6267 Progress Report Period 6/23/67 through 5/2/68  
 Title SST Lubrication System Investigation  
 Contractor EDF Industries, Inc.  
 Prepared by G. Chaccaine Date May 22, 1968

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ENCLOSURE 2GENERAL TEST RIG LAYOUT SCHEMATIC

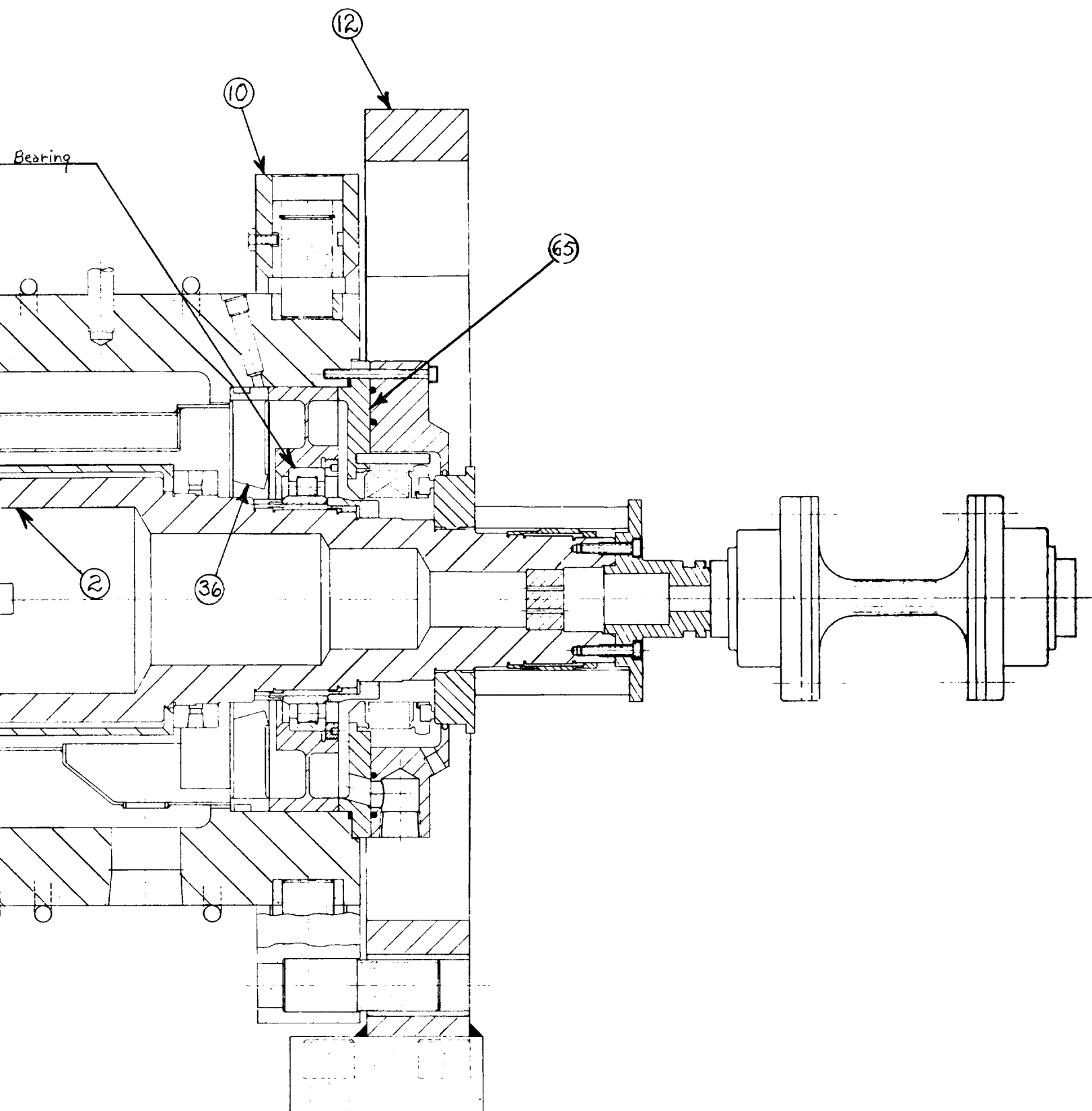


ENCLOSURE 3TEST RIG ASSEMBLY

FOLDOUT FRAME /

SECTION 1









## TEST BEARING DESIGN DATA

2-21204		Design Series II		II		I		I		I		I		I	
BEARING DATA															
1	INDUSTRY PART NO.	4599801													
2	INDUSTRY BEARING NO.	76272-E													
3	BEARING TOLERANCE	ABEC 7													
4	NS & SIZE OF BALLS	21-1/4" DIA.													
5	INTERNAL RADIAL LOOSENESS (UNMOUNTED)	.0008" DIA.													
6	MAX END PLAY (UNMOUNTED)	.001"													
7	DESIGN CONTACT ANGLE	30°													
8	OUTER GROOVE RADIUS AS PERCENT OF BALL DIA.	10%													
9	INNER GROOVE RADIUS AS PERCENT OF BALL DIA.	10%													
10	SHIM WIDTH	.015"													
11	PITCH DIA.	31.50" - 32.50"													
12	CAGE WIDTH (MAX)	1.024"													
13	CAGE SPEC FOR OUT-OF-ROUND (SQUARED)	.0005"													
14	CAGE POCKET CLEARANCE	.001"													
15	BALL GRADE (ABMA)	M50													
16	INNER RING MATERIAL	M50													
17	OUTER RING MATERIAL	M50													
18	BALL MATERIAL	M50													
19	CAGE MATERIAL	M50													
20	CAGE TYPE	M50													
21	BEARING DESIGNED TO OPERATE AT (MAX)	5000 RPM													
22	INNER RING HARDNESS	60 HRC													
23	OUTER RING HARDNESS	60 HRC													
24	BALL HARDNESS	62 HRC													
25	FACE HARDNESS	60 HRC													
26	CAGE RADIUS CLEARANCE ON DIA	.001"													
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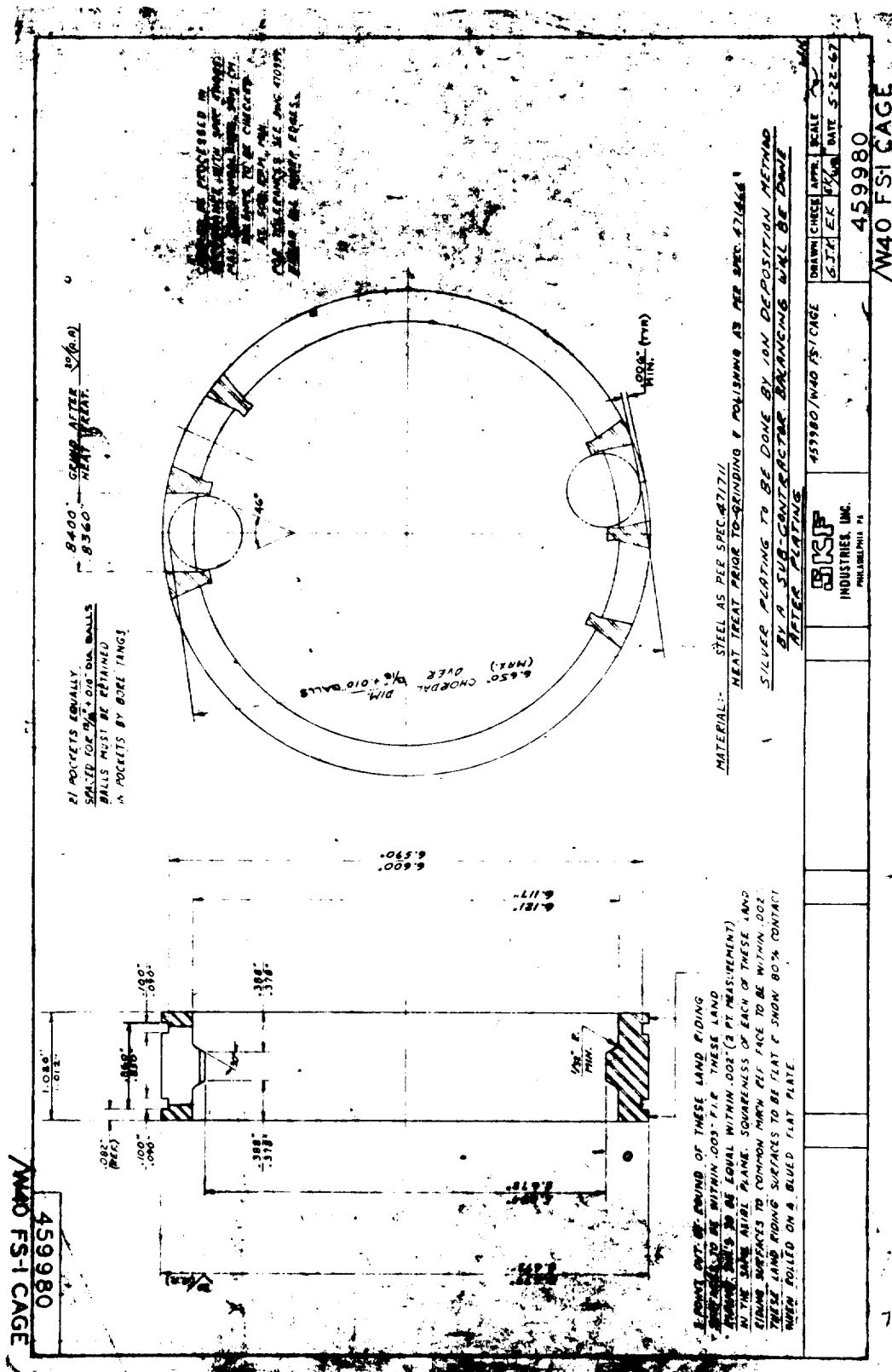
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## ENCLOSURE 6

TABULATION OF TEST ELEMENTS USED IN TASK II TESTS

TEST NO.	LUBRICANT	BEARING USED(1)	(2) CAGE	OIL SEAL (3)		OIL SEAL RUNNER (4)		AIR SEAL (5)		AIR SEAL RUNNER (6)	
				Carbon Mat'l	Design	Plating Mat'l	Design	Carbon Mat'l	Design	Plating Mat'l	Design
1	Mobil Jet II	267101	#2	USG277	70488SN/1	Chrome	700488-10-SN/1	CDJ83	700405SN/2	Chrome	700397SN/A-1
2(7)	Mobil Jet II	267102	#2	USG277	700488SN/1	Chrome	700488-10-SN/1	CDJ83	400405SN/2	Chrome	700397SN/3
3	Mobil Jet II	267103	#3	CDJ83	700489SN/4	Chrome	700488SN/1B	CDJ83	700405SN/2	Chrome	700397SN/2
4	Mobil XRM 154D	267104	#7	CDJ83	700489SN/4	Chrome	700488SN/2	CDJ83	700405SN/2	Chrome Carbide	700405-10-SN/2
6.	Mobil XRM 109F + 10% by wgt. of Kendex 0839	267105	#9	CDJ83	700489SN/10	Chrome	700488SN/1A	CDJ83	700405SN/2	Chrome Carbide	700405-10-SN/2
8.	Mobil XRM 154D	267103	#11	CDJ83	700489SN/4	Chrome Carbide	700488SN/1BCC	56HT	700397SN/7	Chrome Carbide	700405-10-SN/1

- (1) All bearings were made of WB49 steel (459980H).
- (2) All cages which were ion silver plated were made of 4340 steel except the cage in test No. 1 which was made of M1 steel.
- (3) All oil seal bellows were AM 350.
- (4) All oil seal runners were made of AMS 6322.
- (5) All air seal bellows were Inco 718 except the one in test No. 8 which was AM 350.
- (6) All air seal runners in test 1, 2 & 3 were made of AMS 6322 and the runners used in tests 4, 6 & 8 were made of Inco X.
- (7) In order to increase the seating force on the oil seal, the mounting flange of this seal was cut back by .020" prior to assembly (an increase of approximately 15% over the net face load used in previous test).

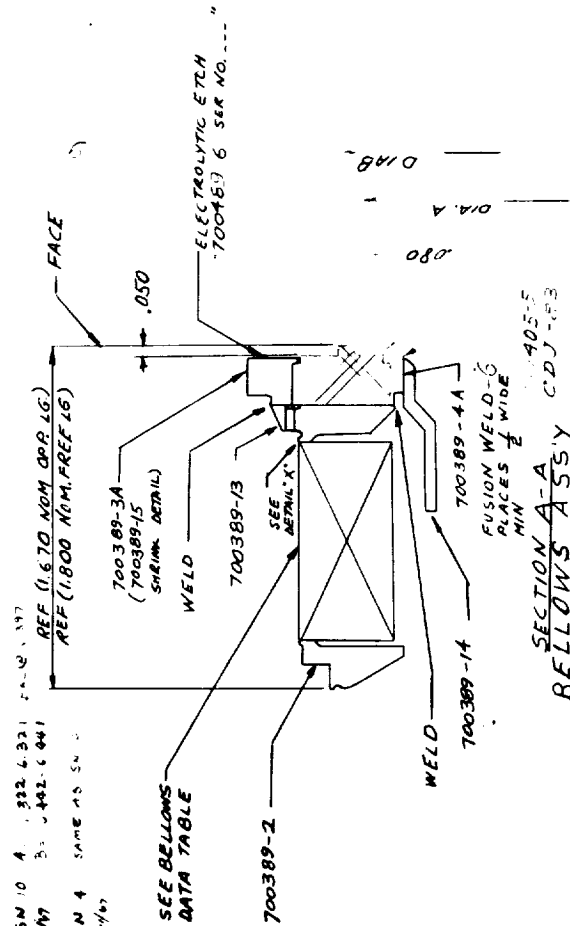
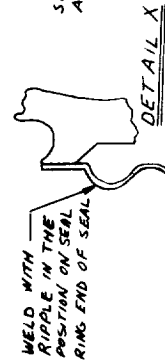
## ENCLOSURE 7

BASIC OIL SEAL DESIGN

**BELLOWS DATA**

DIE NO.	K8115
BELLOWS O.D.	6.830
BELLOWS I.D.	5.890
THICKNESS	.006
HEAT TREAT BELLOWS AREA	.075
NO. CONVOLUTIONS	14
SCALE	
FREE LENGTH	1.050
OPERATING LENGTH	.950
Δ	.730
LOAD (MEASURED)	16
SOLID LENGTH	.253
MATERIAL	AA-350

SEE NOTE #1

RELIEFS 8 DIA.  
WHEEL X .050  
EQ. SPACEDSECTION A-A  
BELLOWS ASSYSEAL RING  
ADAPTER

1. NET LOAD @ 105 PSI = .55 IN.  
 2. λ = FOR OUTWARD FLOW  
 3. DIAS A & B TO BE DETERMINED BY ENGR AFTER TEST. CUT  
 TRIAL DAM (DETAIL DWG 700389-14) BALANCE TEST FIXTURE 600532)  
 4. FACE "C" LAPPED FLAT WITHIN 2 BANDS (HELIUM LIGHT)  
 5. DIAS A & B TO BE CONCENTRIC WITHIN .001 IN. SQUARE WITH FACE ( WITHIN .001 IN. SQUARE)  
 6. USE STANDARD HEAT TREAT PROCEDURE EXCEPT USE 1100°F DRUM TEMPER INSTEAD OF 850°F  
 7. K8115 DE PITCH .085

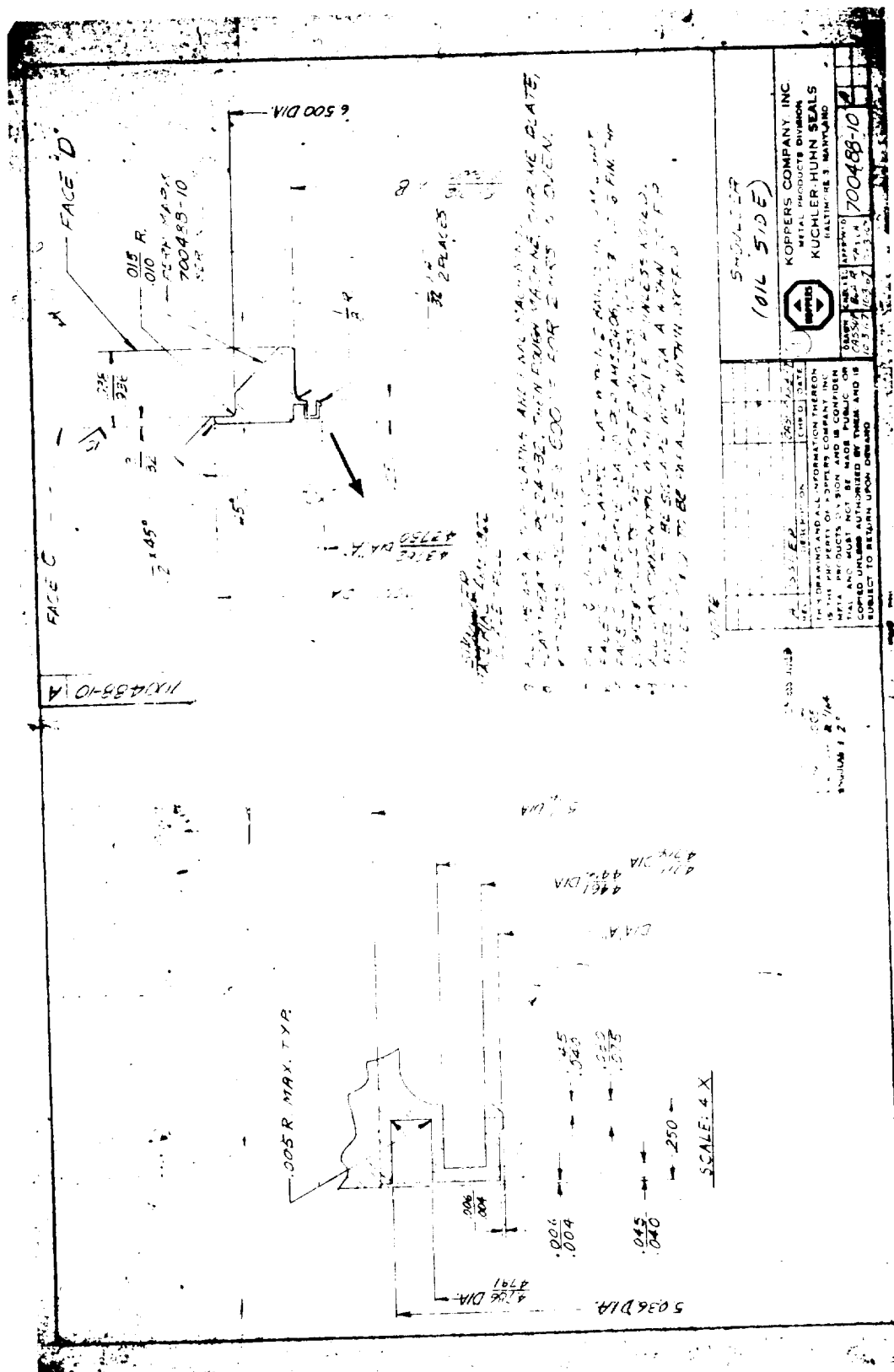
SCALE - FULL

BELLOWS ASSEMBLY  
(OIL SIDE)

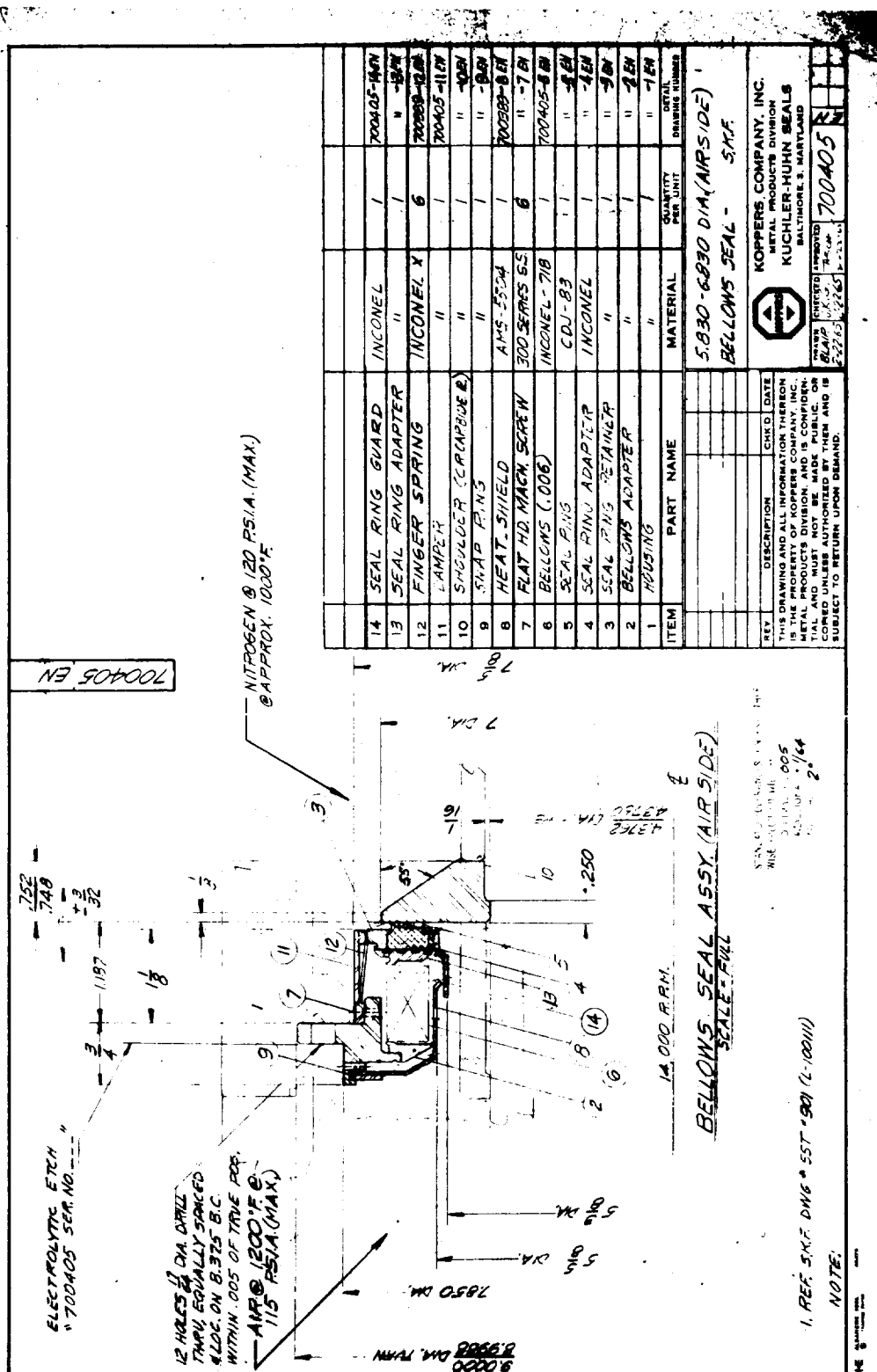
KOPPERS COMPANY INC.

700489-6

### BASIC OIL SEAL SHOULDER DESIGN



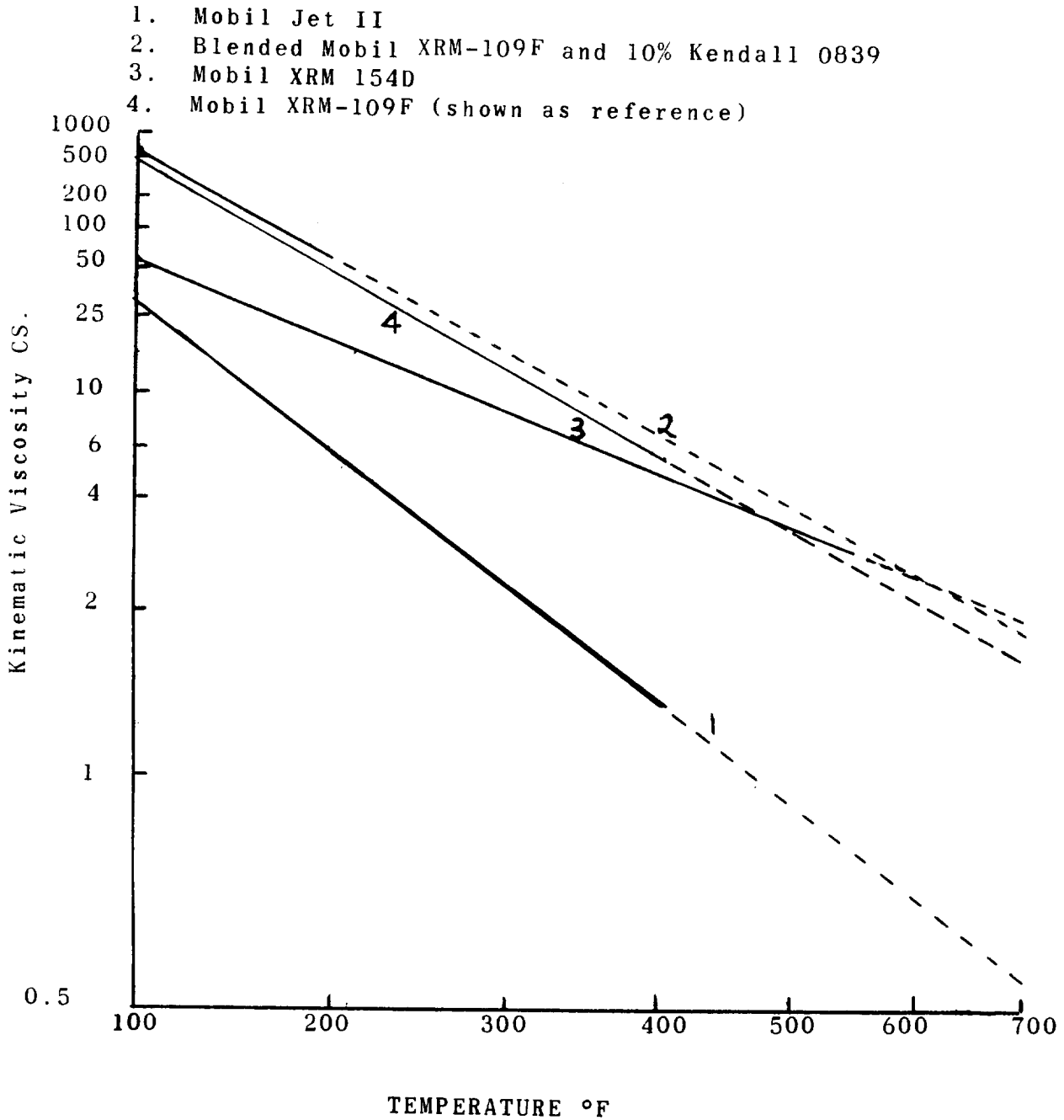
## BASIC AIR SEAL AND SHOULDER DESIGN



## ENCLOSURE 10

VISCOSITY TEMPERATURE RELATION FOR CIRCULATING OIL

From Manufacturer's Data, Except for No. 2



# ENCLOSURE 11

## SUMMARY OF TEST RESULTS IN RECIRCULATING-OIL BIG N2 BLANKET EXCEPT WHERE NOTED

	Oil Flow Rate, gpm	Time at Test Conditions, Hours	Oil Inlet Temp., °F	Test Brg. Outer Ring Inner Ring Temp., °F	Total Seal Leakage Rate, scfm	(PHASE I) Conditions at End of Test Period			Reason for Test Termination	Test Conclusion and Recommendation
						Oil	Test Bearing	Test Seals		
Esso 4040	4 to 5	1.8*	500 to 555	590 to 600	1.5 to 10	Darkened, acid number very high	Considerable glazing, heavy cage pocket wear	Air Seal scored by particles from heater; oil seal OK	Test Brg. Failure	Lubricant not suitable for 600°F bearing operation; do not test @ higher temperature
Mobil XRM-177F	1 to 4	3*	460 to 550	575 to 625	3 to 21	Acid number unchanged, viscosity increased somewhat	Excellent	Oil seal coked and worn from previous use; air seal OK	High Seal Leakage	Lubricant acceptable for 600°F bearing operation; test @ next higher temperature
Sinclair Turbo S-1048	0.5 to 1	3.3*	480 to 500	590 to 625	6 to 8	Somewhat darker, acid number unchanged	Excellent	Oil seal leakage due to incorrect dam position in manufacture; air seal OK	Time-Up*	Lubricant acceptable for 600°F bearing operation; test @ next higher temperature
Monsanto MCS-293	0.5 to 1	1	480 to 500	580 to 600	1	Dark particles; properties unchanged	Outer ring badly flaked cage pockets worn	Excellent	Test Brg. Failure	Insufficient oil for adequate cooling flow; test @ next higher temperature with higher oil flow
Monsanto MCS-293 Open Atmosphere	1	3.2	500 to 525	590 to 620	2 to 12	Dark particles, viscosity increased somewhat; acid number unchanged	Excellent	Oil seal somewhat scored; air seal OK	Time-Up	Suitable for testing @ next higher temperature
Monsanto MCS-293 with Freon	1.25 to 2	3	490 to 515	600 to 620 595 to 630	7 to 11	Viscosity increased, acid number very high	Very good; a few small dirt dents in ball path	Relatively good; some scoring of carbon on oil seal. Air seal leaked excessively	Time-Up	Lubricant suitable at 600°F test at higher temperature
DuPont PR-143 AC	2.5	3	500 to 505	610 to 615 approx. 30°F above outer	10 to 13	Changed from transparent to milky color	Very good; some discoloration caused by fluid	Reasonably good. Oil seal runner showed signs of surface distress	Time-Up	Lubricant suitable at 600°F test at higher temperature
DuPont PR-143 AC	2	3.7	500 to 510	690 to 780 ( 700 for .9 hrs.)	15 to 23	Viscosity increased acid number unchanged	Excellent; slight cage pocket wear brg. discolored	Good Condition	Time-Up	Lubricant suitable at 700°F test at higher Temperature
DuPont PR-143 AC Attempt 800°F (2 brgs.)	0.5 to 2	0.7	490 to 510	600 to 740	5 to 10	Viscosity increased acid number unchanged	One brg. smeared at 600°F (0.5 gpm oil flow) other brg. smeared at 740°F	Some oil seal wear and scoring	Test Brg. Failures	Lubricant suitable at 700°F, endurance test at 650°F, if selected
Sinclair Turbo-S 1048	0.8 to 1	3.3	450 to 500	600 to 700 ( 670 for 1.8 hrs.) 630 to 650	10 to 11	Somewhat darker viscosity increased acid number unchanged	Balls and rings discolored and etched	Good Condition	Time-Up	Lubricant suitable at 700°F; test at higher temperature
Sinclair Turbo-S 1048	1	3.4	495 to 500	730 to 755 ( 750 for 4 hrs) 760 to 780	1 to 3	Dark Viscosity and acid number unchanged	Good; discoloration, slight cage wiping and pocket wear	Good Condition	Time-Up	Lubricant suitable at 750°F test at higher temperature
Sinclair Turbo-S 1048	1	0	500	720	6-10	Dark Viscosity and acid number slightly increased	Mild Surface distress on balls & rings heavy cage pocket wear and wiping	Good Condition	Test Brg.	Lubricant somewhat thermally unstable in the 700-800°F failure range
Mobil XRM-177F	1 to 1.5	7.2	480 to 500	700 to 765 (1.8 hrs at 750) 705 to 765	2-3 except at end of test	Viscosity decreased acid number unchanged	Good; moderate cage pocket wear noticeable. cage wiping	Good Condition	Oil Seal lift off	Lubricant suitable up to 750°F
Sinclair Turbo-S 1048	1 to 1.5	9.7	475 to 520	610 to 640 640 to 670	6 to 26	Viscosity increased. Acid no. increased.	Good; moderate cage pocket wear	Oil seal coked	Oil seal lift off	Lubricant suitable for further endurance testing
XRM-177F ..	1.5	0	500	600 max.	8-10		Good Condition	Good Condition	High Oil Seal Leakage high bearing cavity pressure	Need improved oil seals

\*This denotes tests where there were minor deviations of temperatures other than the test bearing from full test conditions (i.e., test bearing housing, hot air, etc.).

\*\*Attempted long term test; conditions never reached.



## ENCLOSURE 11 (CONT'D)

SUMMARY OF TEST RESULTS IN RECIRCULATING OIL RIGN<sub>2</sub> BLANKET EXCEPT WHERE NOTED

(PHASE II)

	Oil Flow Rate, gpm	Time at Test Conditions, Hours	Oil Inlet Temp., °F	Test Brg. Outer Ring Inner Ring Temp. °F	Total Seal Leakage Rate, scfm	Conditions at End of Test Period			Reason for Test Termination	Test Conclusion and Recommendation
						Oil	Test Bearing	Test Seals		
Mobil Jet II	0.9 to 1.2	2.2	450 to 460	540	13.5 to 20	Viscosity & Acid No. up slight- ly	Cage seized on the O.R. lands	Oil seal and oil seal shoul- der were scored	Test brg. failed due to loss of oil	Test at next higher temperature
Mobil Jet II	1.0 to 1.75	.30	500	500	2.5 to 15.0	Viscosity de- creased. Moder- ate increase in acid number	Slight cage wiping on O.R. lands	Oil seal car- bon complete- ly worn down	Oil seal failure	Test was not run long enough to determine 600°F operation potential. Another test will be run.
Mobil Jet II	0.8 to 1.5	0.2	500	600	4 to 5	Viscosity up acid No. up sharply	Test brg. smeared	Oil seal & Air seal shoulders show signs of chatter	Test brg. failure	Max. short term temp. 550°F
Mobil ARM-154D	3/4 to 3	2.3**	460°F	470 to 490	8 to 12	Viscosity increased. Acid No. unchanged. Heavy Oil Deposits in rig.	Moderate Surface Distress & Heavy Cage Pocket Wear	Good Condit- ion. Oil seal shoulder showed signs of chatt- ering.	Oil Seal Lift-off	Due to high oxygen content another test should be run before definite conclusions are made
Mobil ARM 154D	1.5 to 2.0	3*	480 to 495	630 to 650	2 to 4.7	Very light oil deposits in rig	Slightly glazed	Oil seal scored severely	Oil seal lift off	Suitable as a lubri- cant, however, because of deposit formation not suitable for further running
Mobil ARM 109F + Kendex 0839	1.25 to 1.5	3*	430 490 to 520	515 to 610 680 to 725	0.3 to 0.4 1.8 to 11.4	Viscosity increased high acid No.	Very slight glazing	Oil seal shoulder severely scored	Time-up	Suitable for further long term testing

\* This denotes tests where there were minor deviations of temperatures other than the test bearing from full test conditions (i.e., test bearing housing, hot air, etc.)

\*\* Attempted long term test; conditions never reached.

## ENCLOSURE 12

SUMMARY OF TEST OIL VISCOSITY  
AND ACID NO. BEFORE AND AFTER TEST

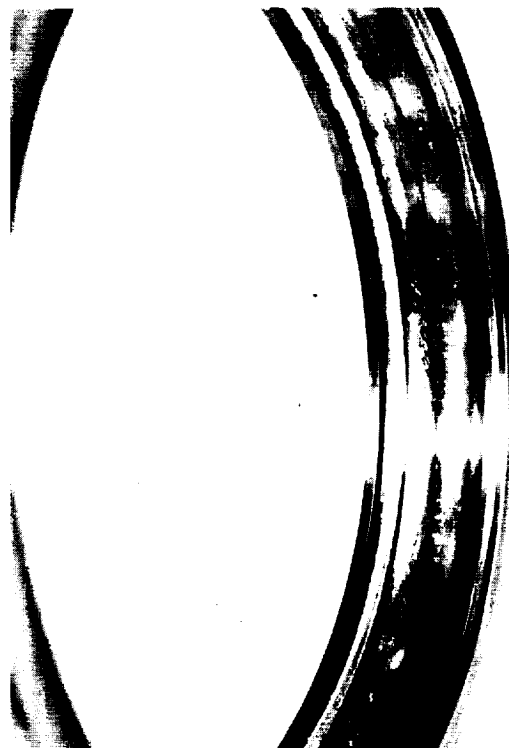
<u>OIL</u>	<u>NEW DEGASSED</u>	<u>USED</u>	<u>CONDITION</u>
Mobil Jet II	Visc. @ 100°F (Cs) Acid No.	27.8 0.1	28.1 0.2
			2.2 hrs. @ 550°F
Mobil Jet II	Visc. @ 100°F (Cs) Acid No.	27.8 0.1	23.9 0.2
			0.7 hrs. @ 550°F
Mobil Jet II	Visc. @ 100°F (Cs) Acid No.	27.8 0.1	28.7 0.4
			0.2 hrs. @ 600°F
Mobil XRM 154D	Visc. @ 100°F (Cs) Acid No.	55.3 0.2	60.6 0.2
			1.1 hrs. from 400 to 500°F
Mobil XRM 109F + 10% by wgt. Kendall 0839	Visc. @ 100°F (Cs) Acid No.	550.4 0.05	588.8 0.11
			3 hr. @ 600°F 3 hr. @ 700°F
Mobil XRM 154D	Visc. @ 100°F (Cs) Acid No.	55.4 0.05	66.5 0.2
			3 hrs. @ 650°F

ENCLOSURE 13

Test Bearing Parts After 550°F Mobil Jet  
Oil II Screening Run for 2.2 Hours



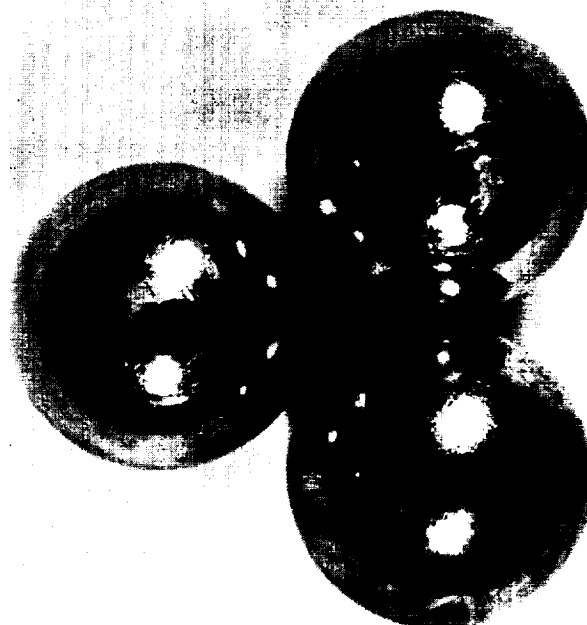
a) Inner Race



b) Outer Race



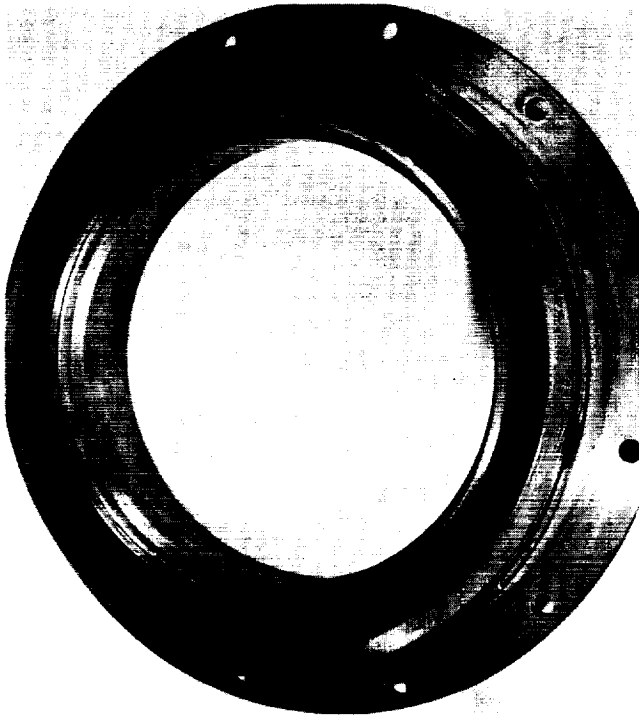
c) Cage



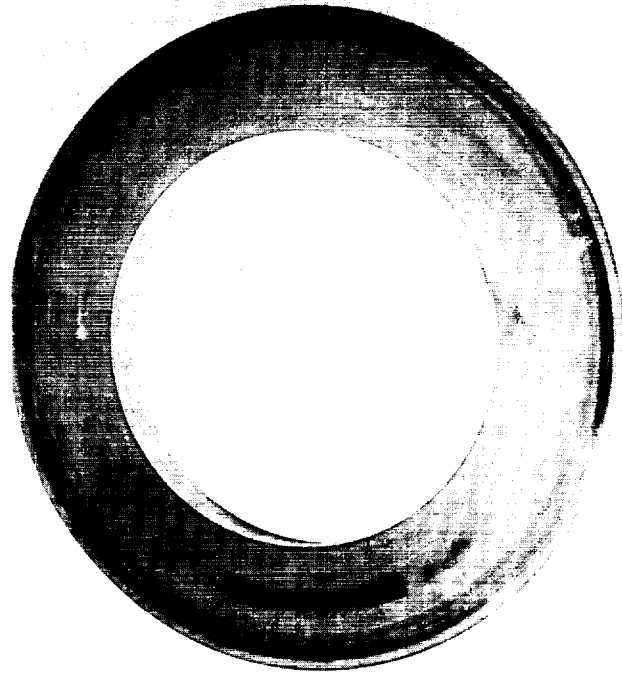
d) Balls

ENCLOSURE 14

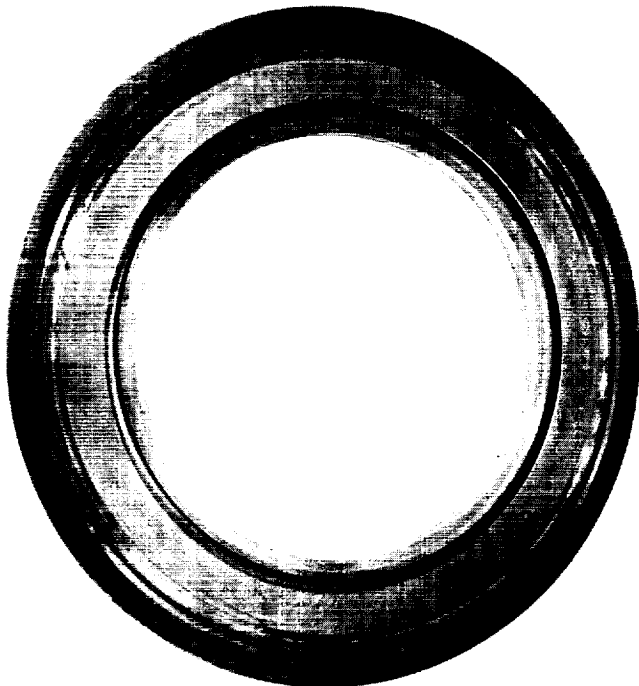
Test Seals Parts After 550°F Mobil Jet  
Oil II Screening Run for 2.2 Hours



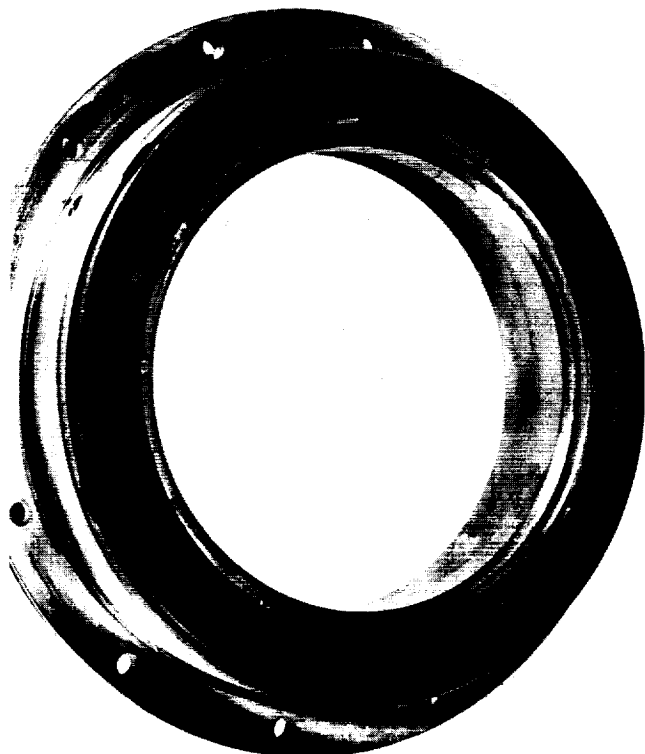
a) Air Seal



b) Air Seal Runner



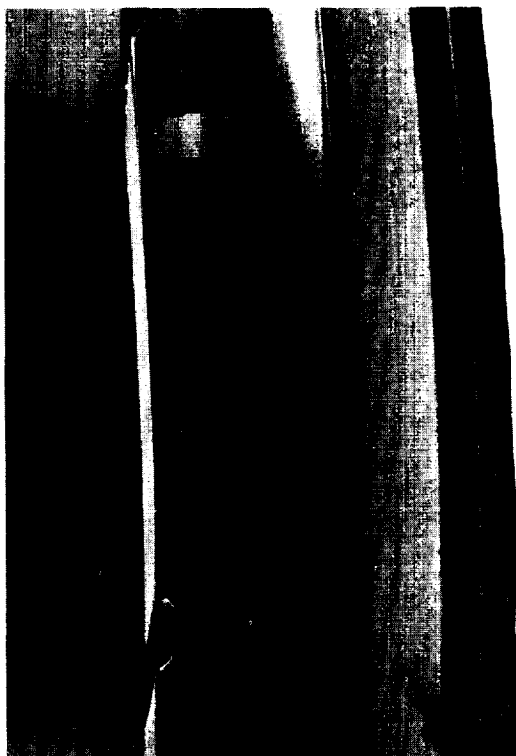
c) Oil Seal



d) Oil Seal Runner

ENCLOSURE 15

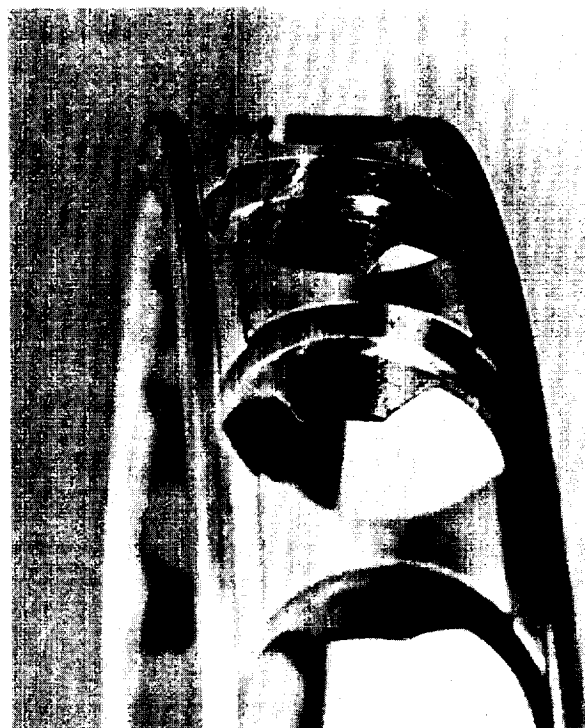
Test Bearing Parts After 560°F Mobil Jet II  
Screening Run for 1.0 Hours



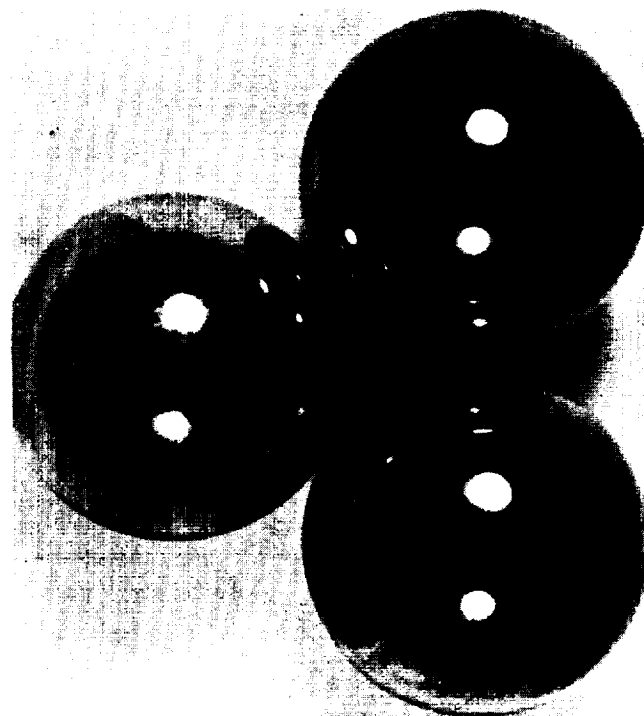
a) Inner Race



b) Outer Race.



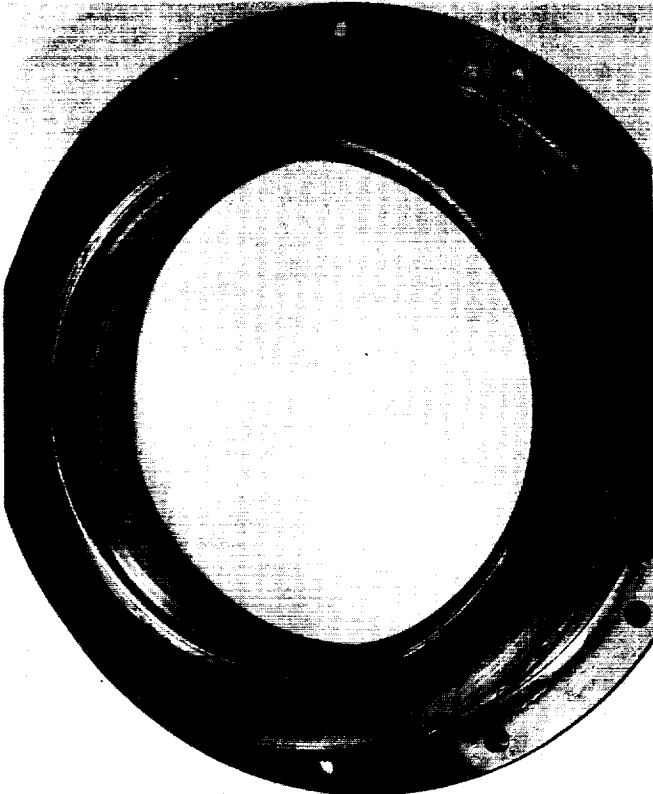
c) Cage



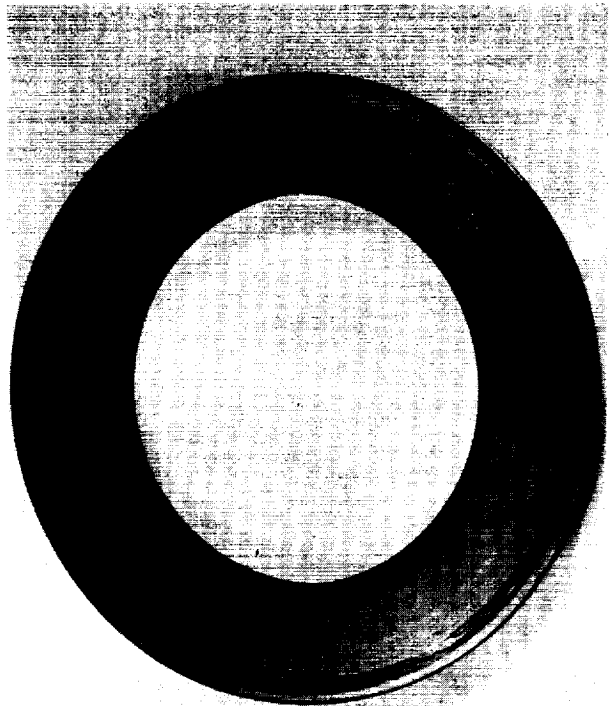
d) Balls

ENCLOSURE 16

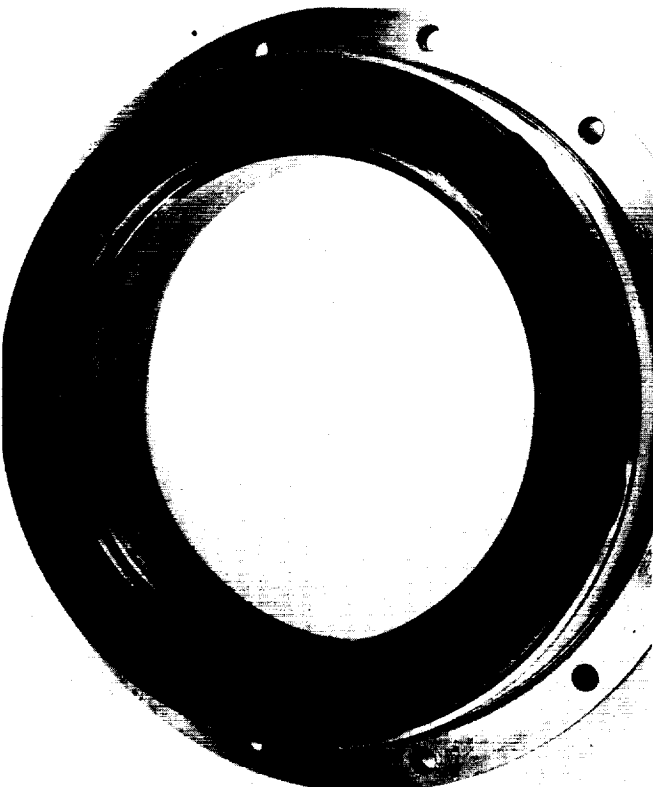
Test Seals Parts After 560°F Mobil Jet  
Oil II Screening Run for 1.0 Hours



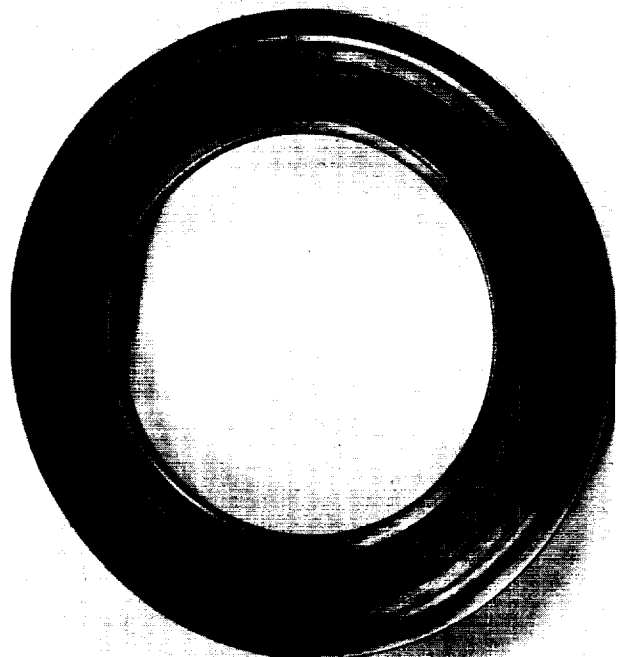
a) Air Seal



b) Air Seal Runner



c) Oil Seal



d) Oil Seal Runner

ENCLOSURE 17

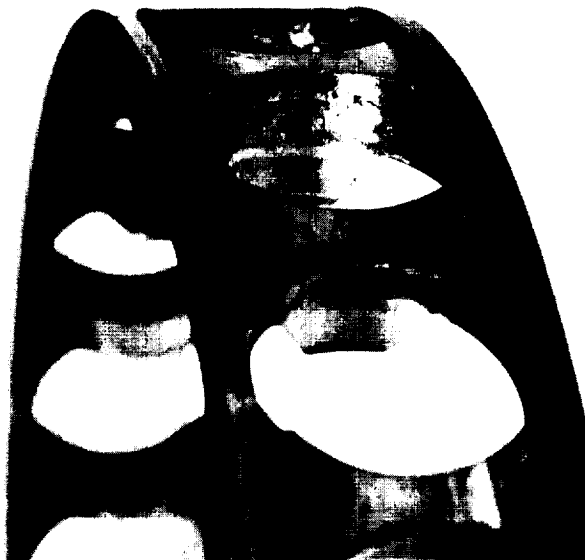
Test Bearing Parts After 600°F Mobil Jet  
Oil II Screening Run for 1.4 Hours



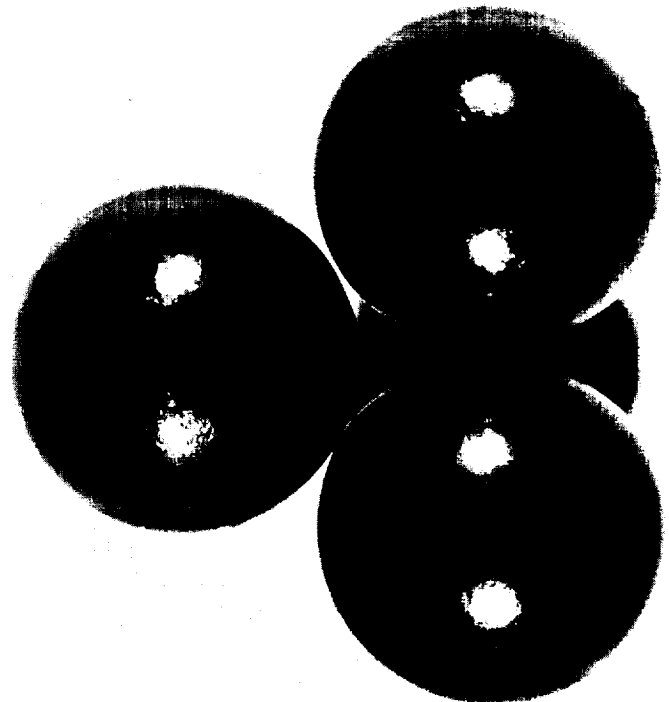
a) Inner Ring



b) Outer Ring



c) Cage

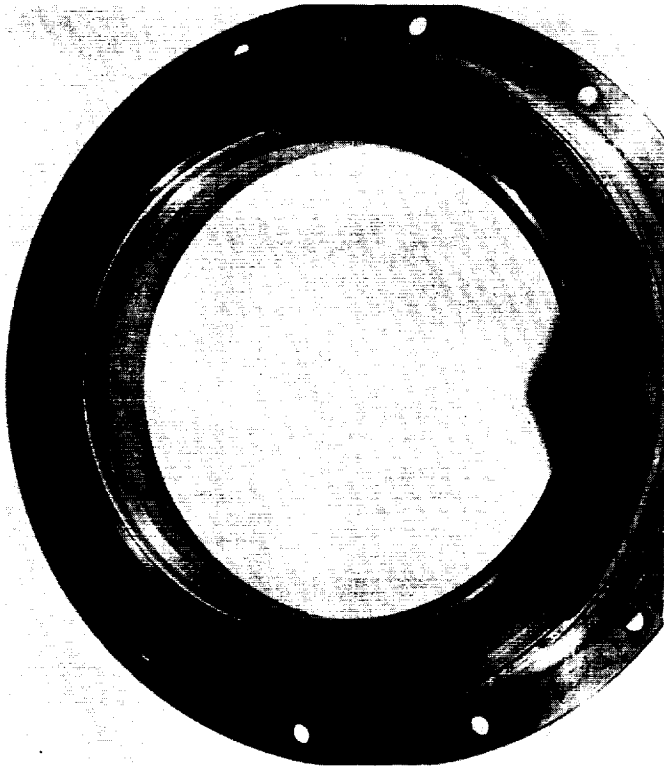


d) Balls

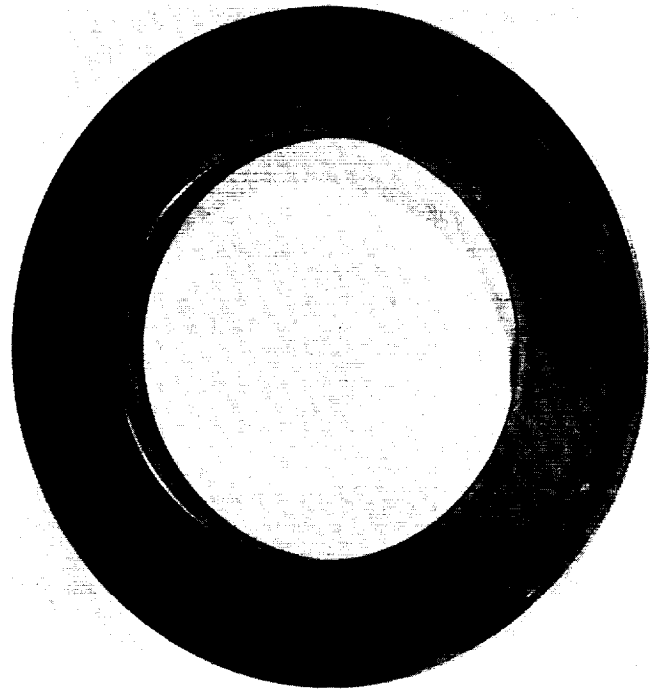
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ENCLOSURE 18

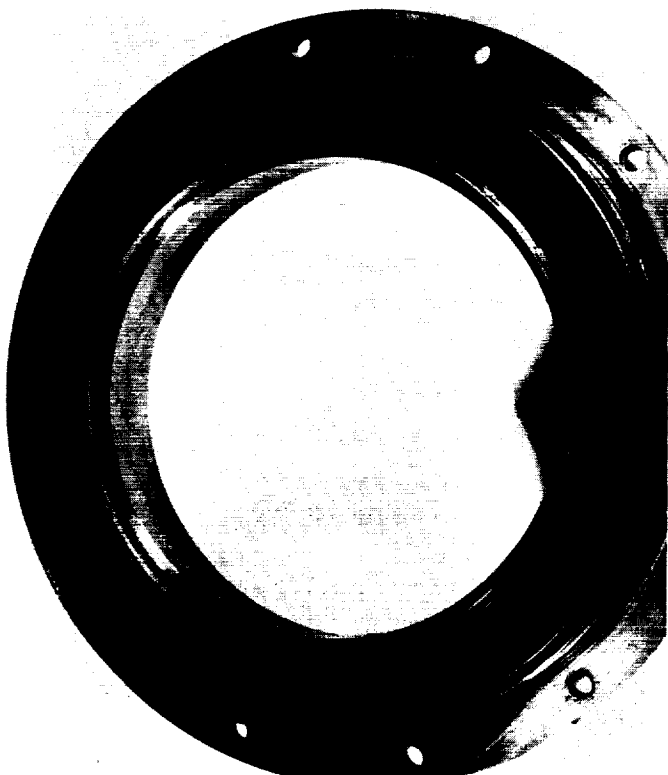
Test Seals Parts After 600°F Mobil Jet  
Oil II Screening Run for 1.4 Hours



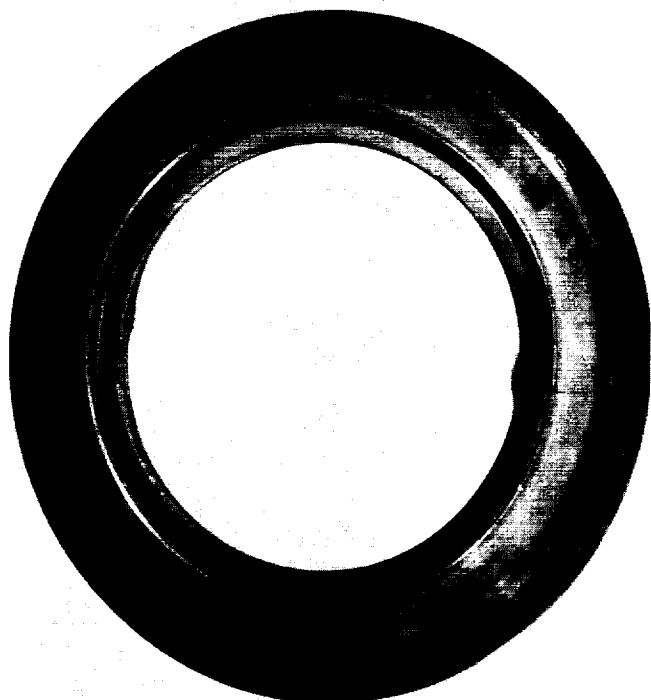
a) Air Seal



b) Air Seal Runner



c) Oil Seal



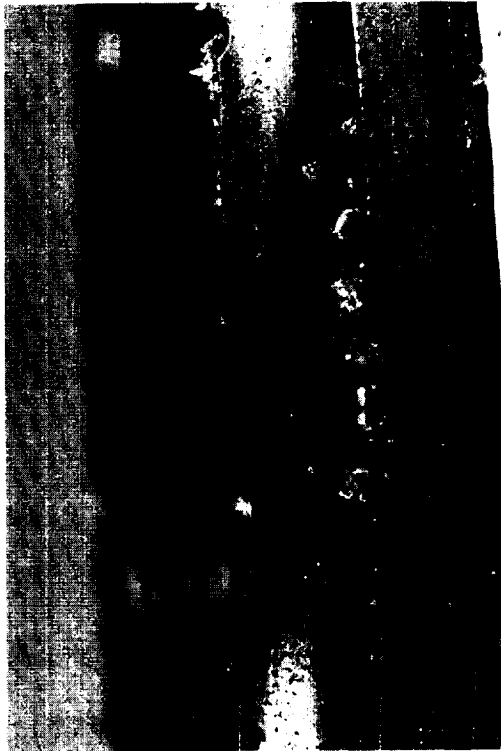
d) Oil Seal Runner



ENCLOSURE 19

Test Bearing Parts After 500°F Mobil XRM 154 D  
Screening Run for 2.3 Hours

Note: Heavy Oil Decomposition Products on Parts



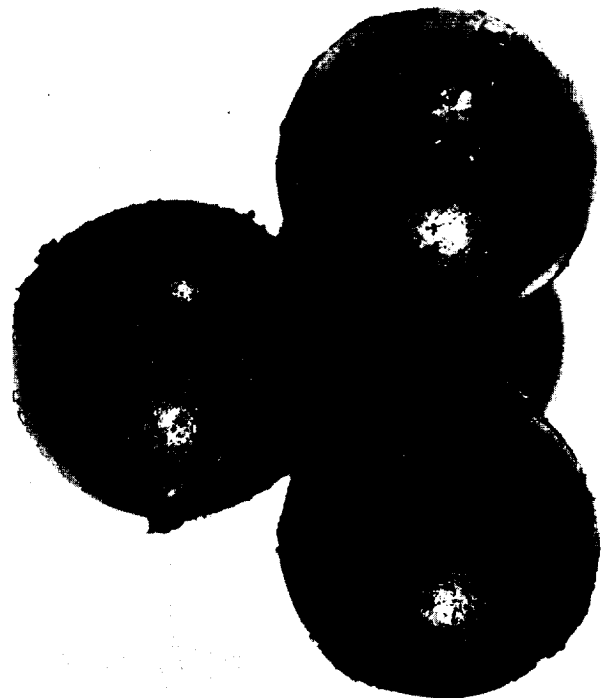
a) Inner Race



b) Outer Race



c) Cage

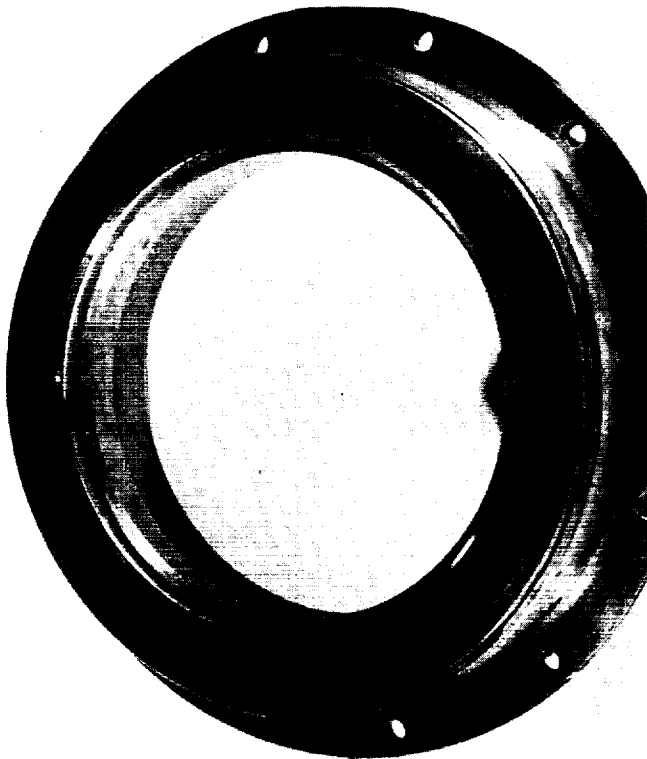


d) Balls

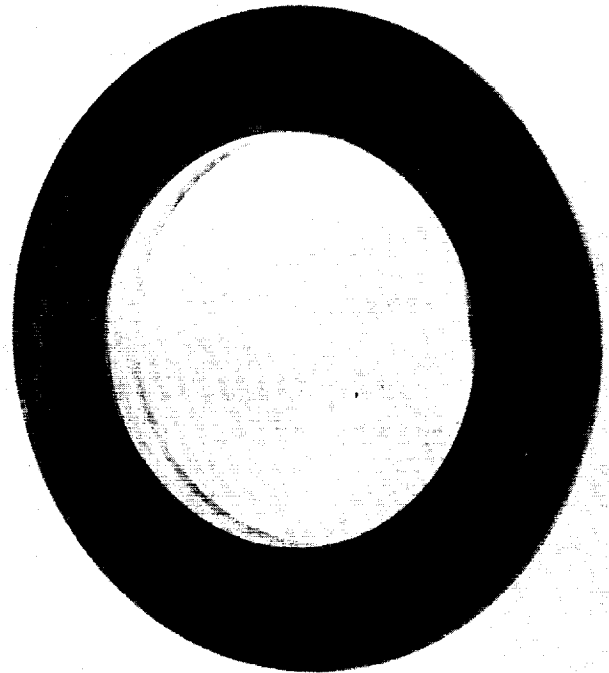
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ENCLOSURE 20

Test Seals Parts After 500°F  
Mobil XRM 154D Oil Screening Run For 2.3 Hours



a) Air Seal



b) Air Seal Runner



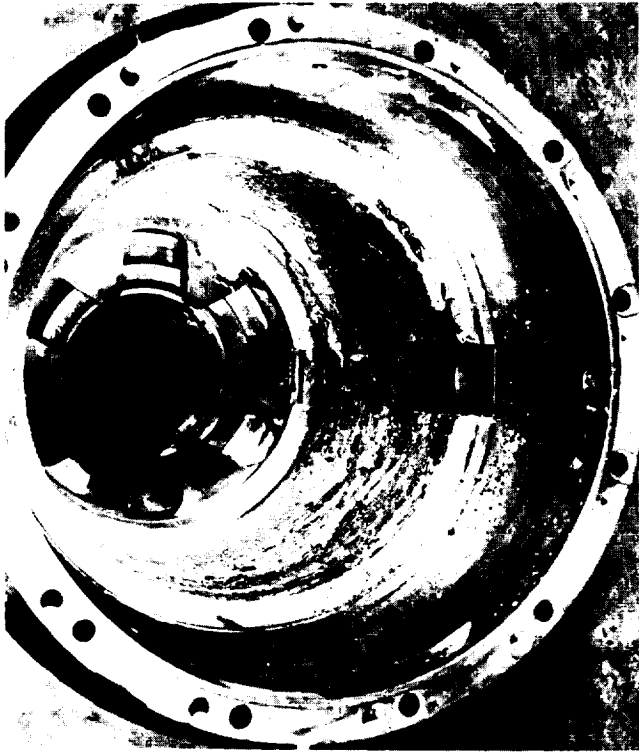
c) Oil Seal



d) Oil Seal Runner

ENCLOSURE 21

Test Rig Parts After 480°F Mobil XRM 154D Oil Screening Run For 1.2 Hrs.  
Note: Heavy Oil Decomposition Products on all Parts



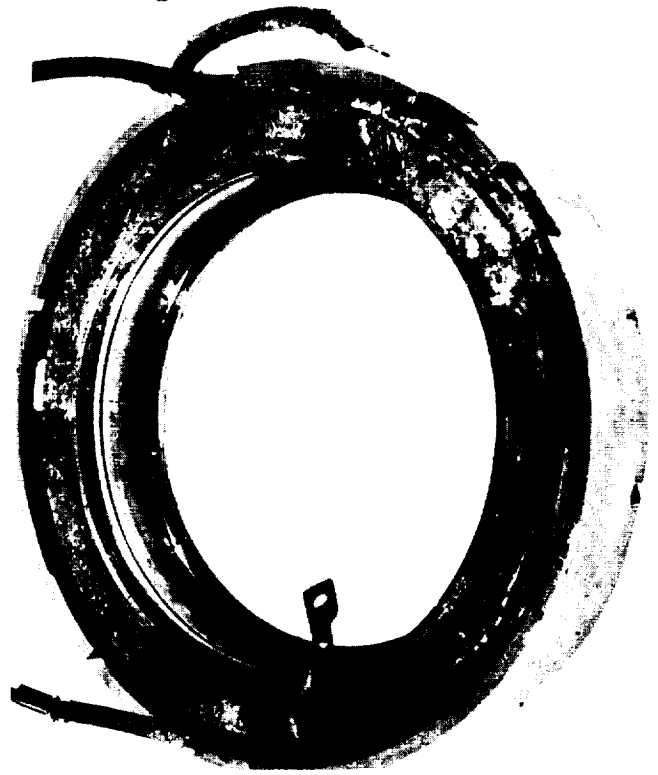
Test Bearing Housing



b) Heat Shield



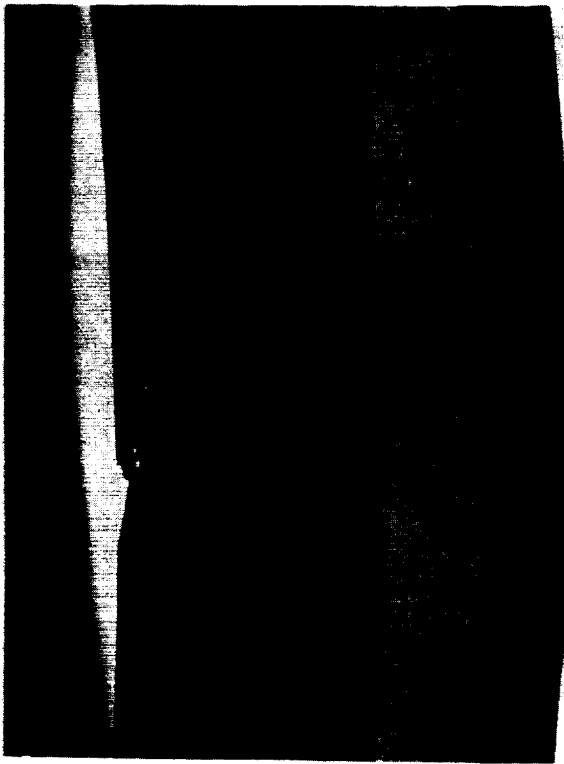
c) Shaft



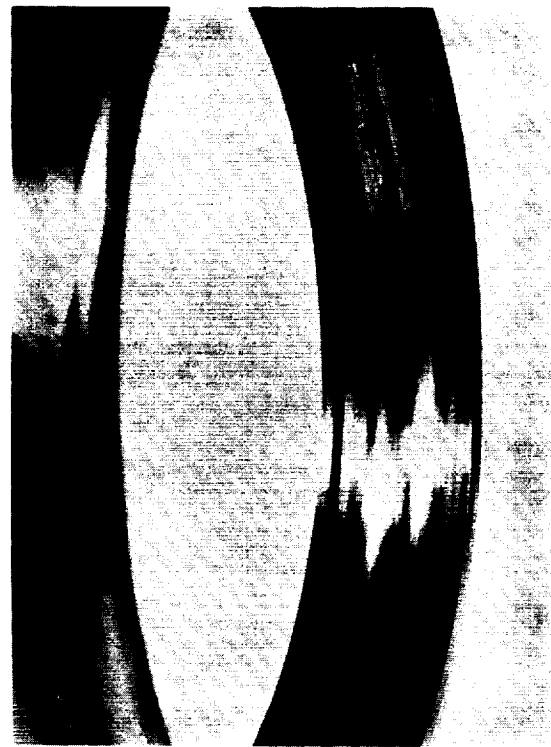
d) Housing Heater

ENCLOSURE 22

Test Bearing Parts After 650°F  
Mobil XRM 154D Oil Screening Run for 3.0 Hours



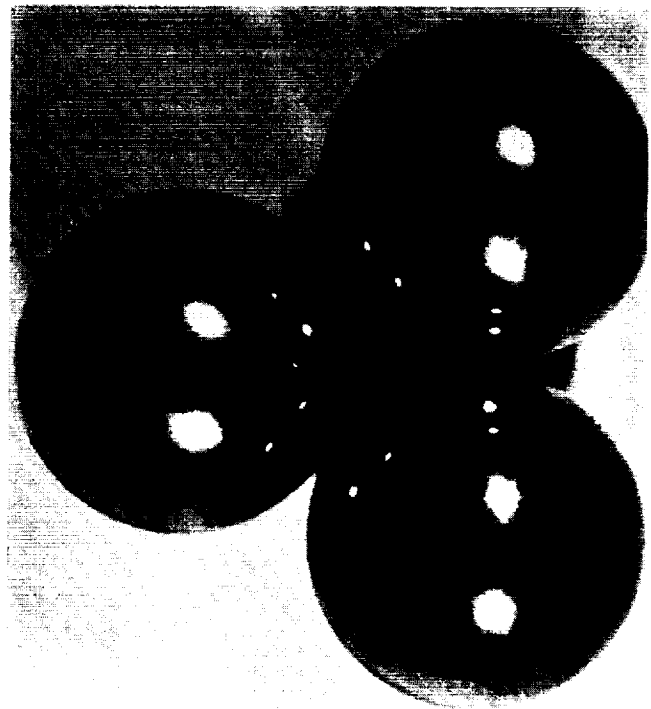
a) Inner Race



b) Outer Race



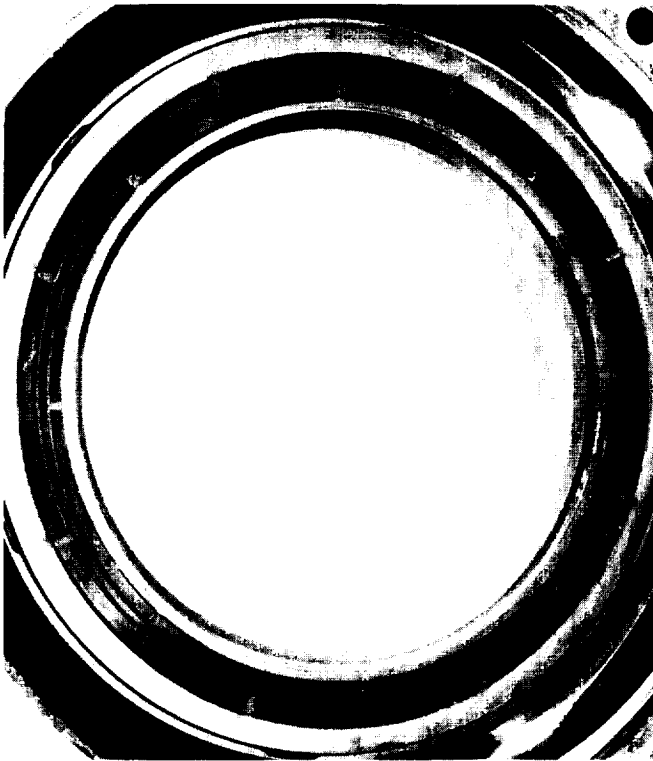
c) Cage



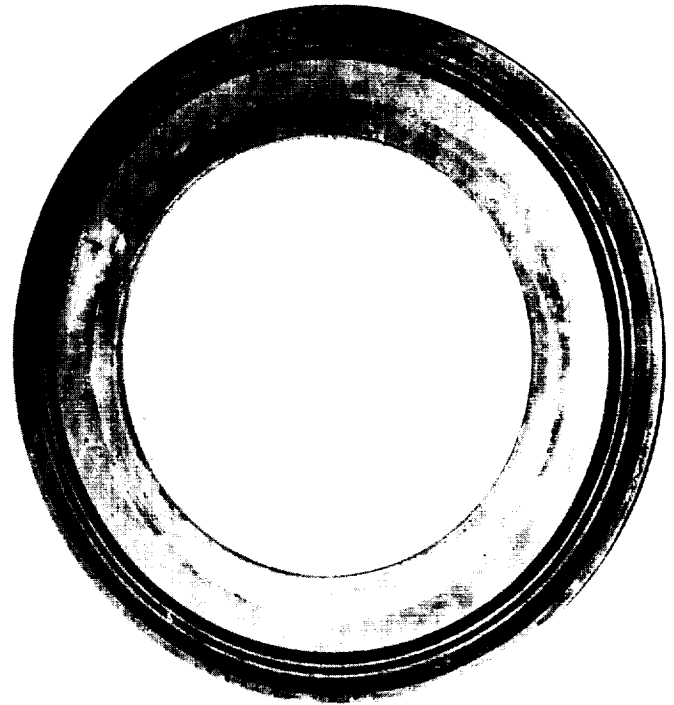
d) Balls

ENCLOSURE 23

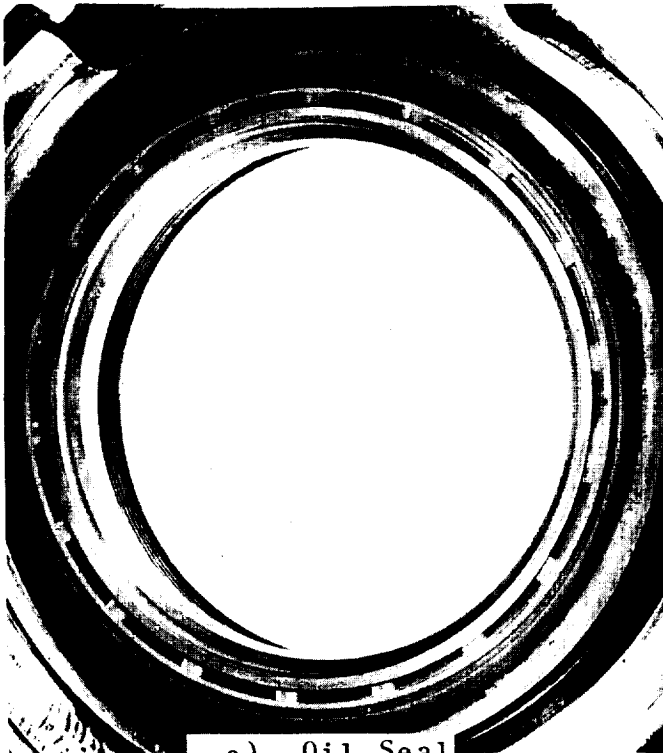
Test Seals Parts After 650°F  
Mobil XRM 154D Oil Screening Run For 3.0 Hours



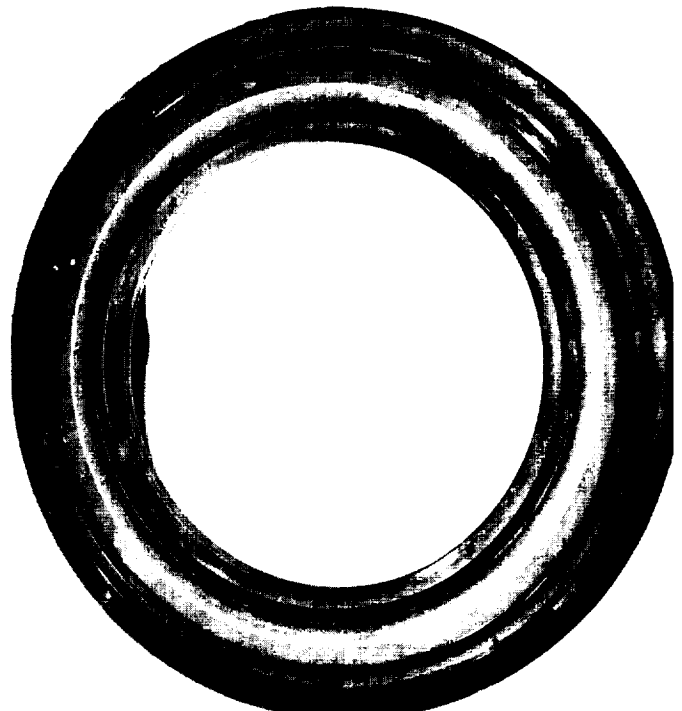
a) Air Seal



b) Air Seal Runner



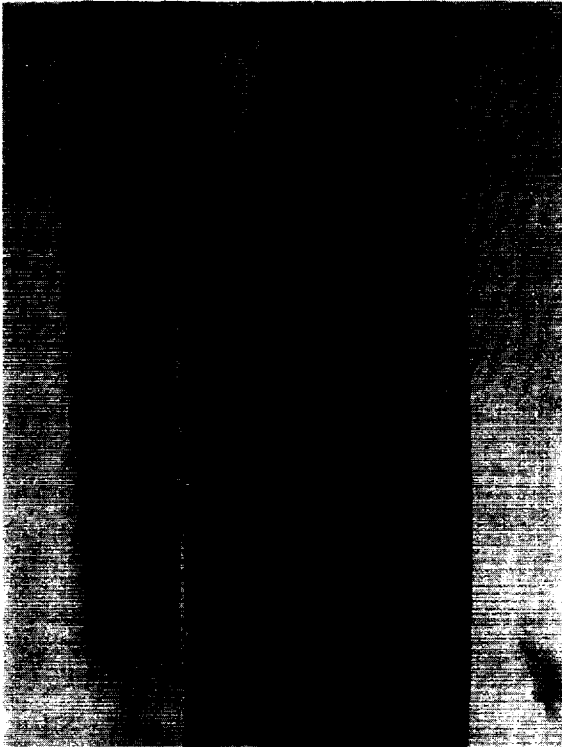
c) Oil Seal



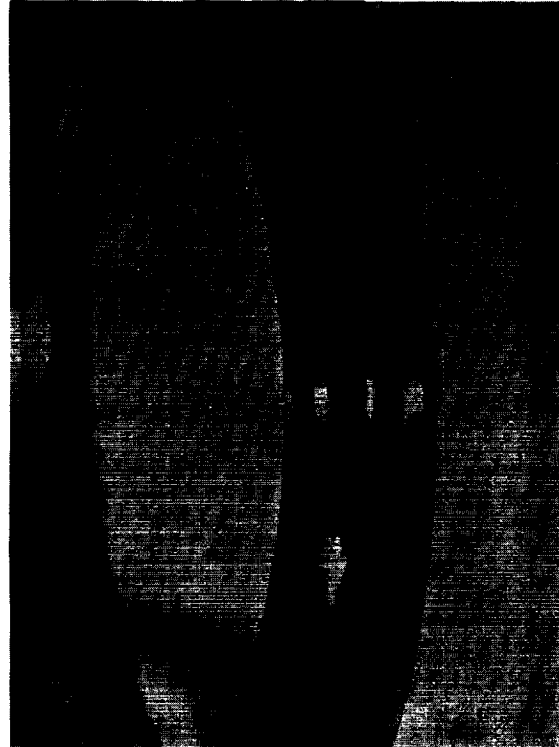
d) Oil Seal Runner

ENCLOSURE 24

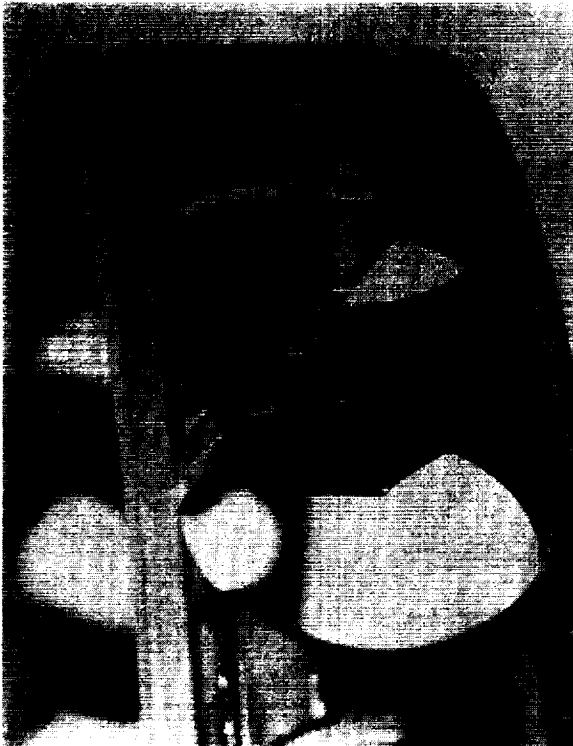
Test Bearing Parts After 700°F Mobil XRM 109F and 10% by  
Weight of Kendex 0839 Oil Screening Run For 6.0 Hours



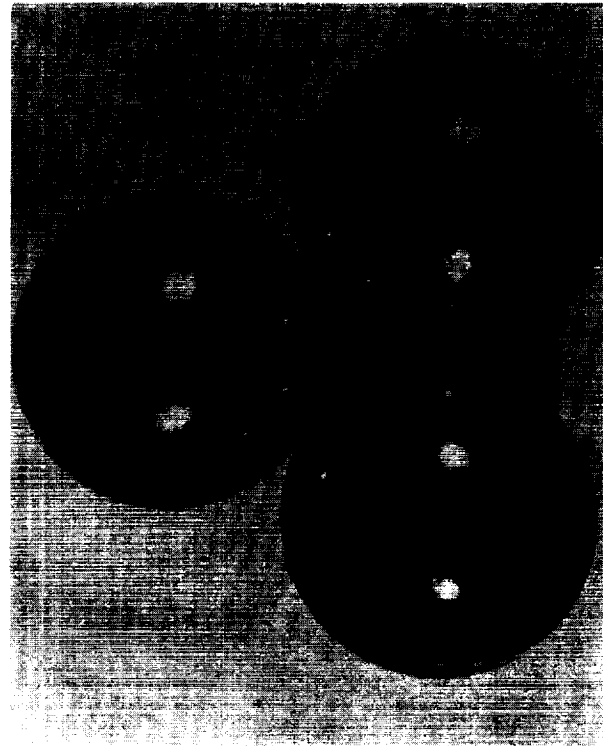
a) Inner Race



b) Outer Race



c) Cage

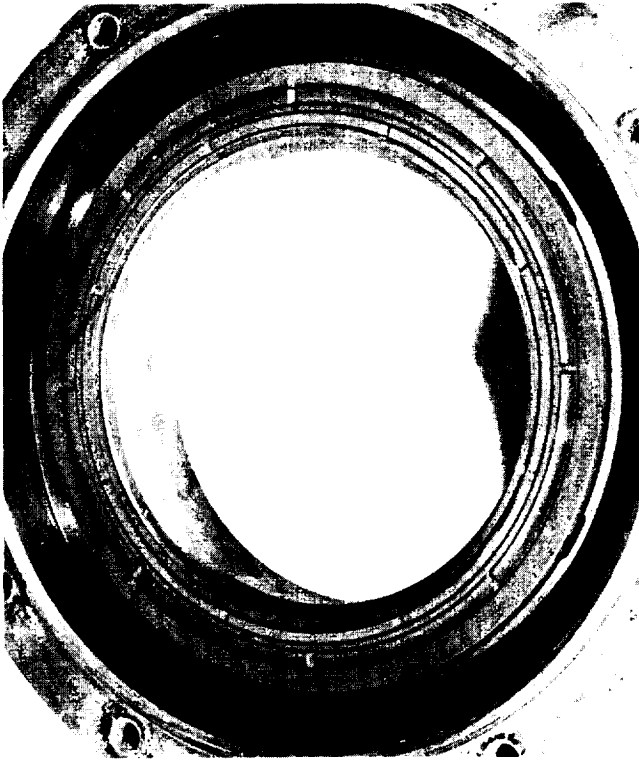


d) Balls

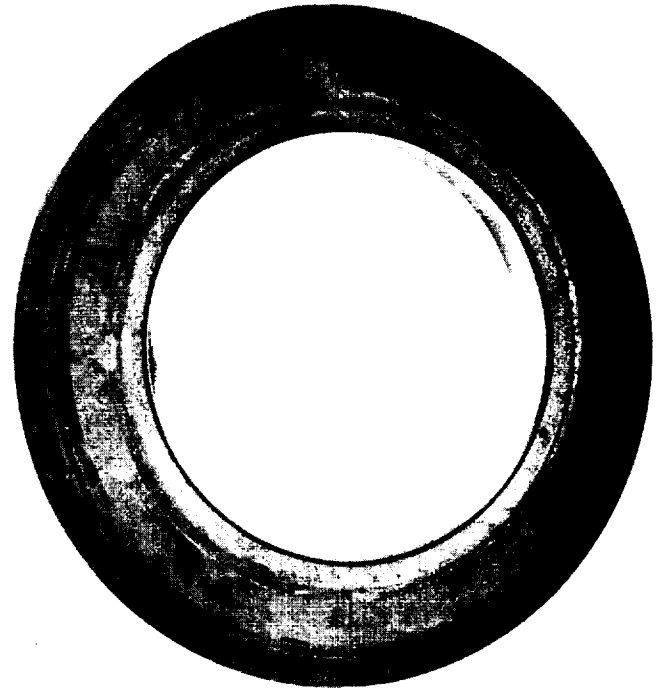
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ENCLOSURE 25

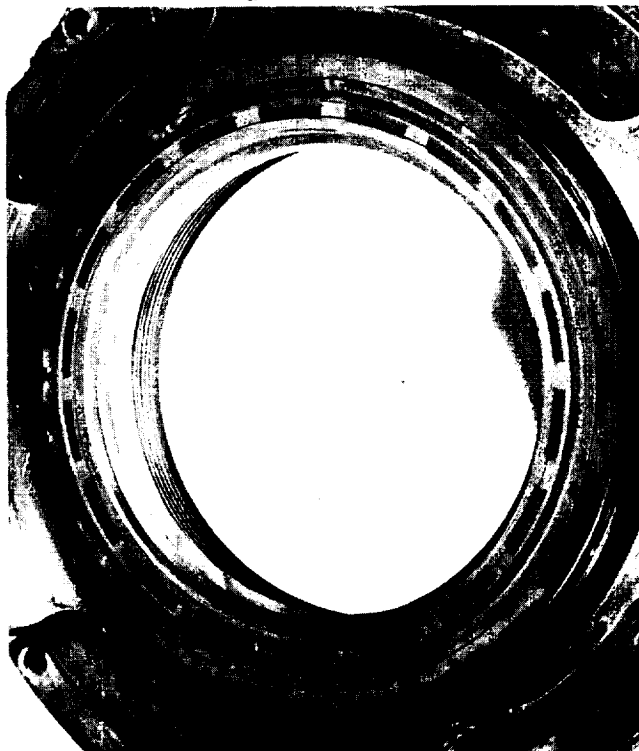
Test Seals Parts After 700°F Mobil XRM 109F and 10% by  
Weight of Kendex 0839 Oil Screening Run For 6.0 Hours



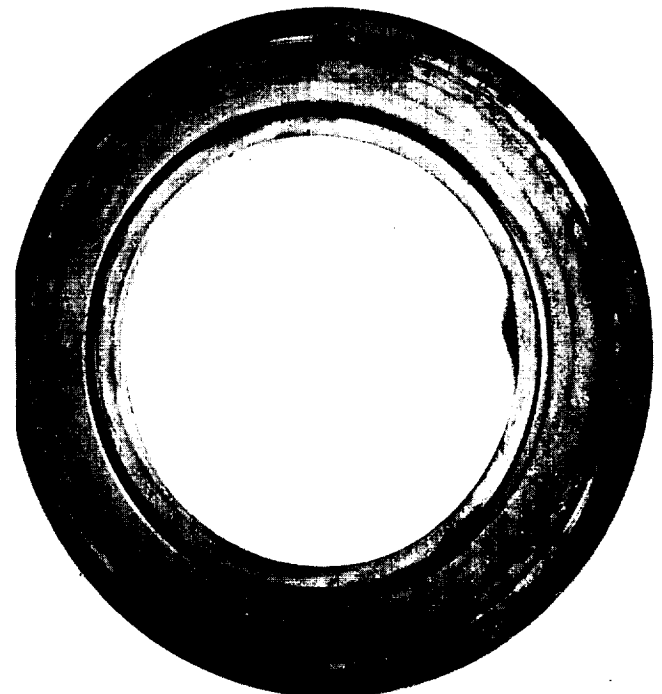
a) Air Seal



b) Air Seal Runner



c) Oil Seal



d) Oil Seal Runner





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APPENDIX I



APPENDIX IPhase II - Scope of Work (Part d, Item 2, Amendment 8, NASA Contract NAS3-6267)

The Contractor shall furnish the necessary personnel, services, facilities and materials, and otherwise do all things necessary for, or incident to, the work described below:

Task I - Test Rig and Test Bearings, Seals and Fluid Selection

The Contractor shall provide the Contractor-owned bearing and seal assembly test rig that is equipped with a recirculating lubrication system and was used previously under this contract. The temperature distribution on the test bearing and seal assembly and test cavity shall be such that no part is at a temperature of more than 25°F below the outer ring bearing test temperature. To insure that the heat flow path will be from the inner to the outer ring of the test bearing, the inner ring temperature shall be maintained at least 10°F hotter than the outer ring temperature. Oxygen content shall be monitored in the test cavity.

A. Bearings

1. The primary test bearing shall be a split-inner-ring ball bearing as made for Phase I, of this contract. Thirteen (13) bearings shall be supplied by NASA from consumable-electrode-vacuum melted (CVM) WB49 steel and six (6) bearings from (CVM) M50 steel.
2. The bearings shall have design features which provide the following:
  - a. Cages shall be made of AISI 4340 steel with silver coating applied by vacuum ion deposition method. (Seven (7) back-up cages of M1 steel shall also be supplied by NASA).
  - b. Design changes as proposed by the contractor and agreed to by the NASA Project Manager to permit operation at DN value of  $1.75 \times 10^6$  and at outer race temperatures to 700°F.
3. The bearing has a specific dynamic capacity of at least 21,000 lbs. as defined by the Anti-friction Bearing Manufacturers Association (AFBMA). Calculated maximum

induced contact stress shall be approximately 200,000 psi. The design provides a bearing L<sub>10</sub> life of 500 hours as calculated by AFBMA methods based on a thrust load of 3,280 lbs. and a speed of 14,000 rpm.

B. Seals

1. The test seal shall be constructed as a pressure-balanced double face seal assembly and be of the type used in Phase I of this contract, i.e., there shall be an air seal exposed to 1200°F air temperature and a pressure drop across the seal of nominally 5 psi; and an oil seal exposed to the bearing chamber oil temperature and a pressure drop across the seal of 100 psi. The seal springs and bellows shall be made of Inco 718 or equivalent high temperature material. Damping shall be used.
2. The seal shall have a mean face diameter of 6.33" (390 fps surface speed).
3. All seals shall have seal carbons of National Carbon CDJ-83 and shall otherwise be made according to Koppers Company Drawings No. 700473 for the oil seal and 700405 for the air seal. Two oil seals and two air seals shall be provided by NASA, and three oil seals and three air seals shall be provided by the Contractor.
4. A continuous leakage in excess of 5 scfm, or as directed by the NASA Project Manager, across any single seal under the conditions described above shall be considered a seal failure. Gas flowmeters in the nitrogen and high-pressure air lines and mass spectrometer monitoring of the interseal and bearing test chambers, using a helium tracer in the nitrogen blanketing gas, shall be used to provide maximum flexibility in tracing seal leakage paths.
5. Nitrogen gas shall be supplied to the space between the two seals at a pressure of about 5 psi higher than the 1200°F air pressure, and the test cavity shall be vented overboard against a back-pressure valve providing a test cavity pressure of the order of 6 psi. Total oxygen content of leakage gases into the test cavity shall not exceed 0.5%.

### C. Fluid Selection

The following three fluids shall be supplied by the Contractor from a single controlled lot of each fluid:

1. Mobil XRM 109F plus 10 weight percent of 20,000 SUS Kendall high molecular weight paraffinic resin, (quantity not exceeding 230 gallons of Mobil XRM 109F plus 25 gallons of Kendall Resin).
2. Mobil XRM-154D modified silicone, (quantity not exceeding 80 gallons supplied from a lot of 230 gallons).
3. Mobil Jet II advanced ester, (quantity not exceeding 230 gallons supplied from a lot of 280 gallons).

### Task II - Screening Tests

The Contractor shall perform a series of screening tests using the three (3) Task I fluids, WB49 test bearings and Inco 718 seals in the bearing and seal assembly to establish the extent of corrosion, system deposits and mode of failure of the closed and inert recirculating lubrication system under simulated Mach 3 SST engine flight conditions.

#### A. Test Procedure

1. The bearing shall be tested under a thrust load of  $P = 3280$  lbs. The experimental rig shall be operated under each set of conditions (type of fluid and bearing temperature) for a duration of three hours or until failure is indicated by (a) a sudden rise in the test bearing torque, temperature or vibration, or (b) an increase in seal leakage to an excessive leakage rate, or (c) excessive coking of the oil. A series of runs consist of using a lubricant from the selected list, previously degassed, in a nitrogen-inert recirculating system at an oil-in temperature of  $450^{\circ}\text{F} \pm 10^{\circ}\text{F}$  for the first run and  $500^{\circ}\text{F} \pm 10^{\circ}\text{F}$  subsequent runs. Each series of runs shall start with the bearing outer-ring temperature maintained at  $550^{\circ}\text{F}$  for the first run and  $600^{\circ}\text{F}$  for the second run. If the first full three-hour run is conducted without failure, the second run shall immediately begin without rig shut down. If the second

full three hour run is conducted without failure, the test elements and rig shall be disassembled, inspected and cleaned and the third and final run with the fluid shall be conducted at an outer ring temperature of 700°F. After a failure, or after successful completion of the full three hour run at 700°F, the rig shall be disassembled, inspected and cleaned and the next series of runs started. This procedure shall be followed for each lubricant to establish the maximum bearing operating temperature (up to 700°F) for each lubricant under inert blanketing conditions.

2. The effluent lubricant, which is expected to be at a temperature in excess of 525°F as measured at the oil inlet from the rig test cavity, shall be cooled by a heat exchanger down to 450°F  $\pm$  10°F for the first run with each oil and to 500°F  $\pm$  10°F for all other test runs before being returned to the test cavity. The volume of each lubricant in the system shall be kept between 4 and 5 gallons. The oil flow rates used shall be representative of advanced engine design practice as approved by the NASA Project Manager.
3. All lubricants shall be degassed either for a 72 hour period at room temperature or at a temperature not exceeding 200°F for a period of at least one hour before running all inert tests, by means of a mechanical pump capable of maintaining a pressure of  $10^{-3}$  torr and kept under an inert gas blanket after degassing except while being introduced into the test system. New bearings shall be used for each lubricant series and after each bearing failure. Rework of seals is permitted to insure maximum utilization of usable seal components, provided such rework does not affect the test results.

### Task III - Baseline, Qualifying, and Endurance Tests

#### A. Test Procedures for Baseline Test

The Contractor shall obtain baseline data with the recirculating oil system, using air to replace the nitrogen supplied to the interseal cavity only. (This test shall be run under conditions selected to avoid explosion hazards). The lubricant shall be the advanced ester as specified in paragraph C. of Task I. A 50 hour

run shall be made under these conditions with a 400°F  $\pm$  10°F oil-in temperature and a 500°F bearing outer-ring temperature with M50 bearing material. This test shall be run in periods of from 5 to 10 hours duration running time between which the test rig shall be shut down and allowed to cool for a period sufficient to reach a bearing temperature not exceeding 250°F (probably of 1 to 2 hours) before starting another test cycle. No helium tracer will be used in this test.

B. Test Procedures for Qualifying Tests

The Contractor shall perform qualifying tests of the closed and inert recirculating lubrication system. Based on the analysis of results from the screening tests in Task II, two lubricants and corresponding bearing outer race temperatures (not in excess of 700°F) shall be specified by the NASA Project Manager for running these tests. Two tests shall be conducted using the two selected fluids, with WB49 bearing material, for a total running time of 50 hours each. These qualifying tests shall be run in periods of from 5 to 10 hours duration running time between which the test rig shall be shut down and allowed to cool for a period sufficient to reach a bearing temperature not exceeding 200°F (probably of 1 to 2 hours) before starting another test cycle.

C. Test Procedure for Endurance Tests

The Contractor shall perform endurance testing of the closed and inert recirculating lubrication system. Two (2) lubricants and corresponding bearing outer race temperatures (not in excess of 700°F) shall be specified by the NASA Project Manager based on the evaluation of results from Task II and paragraph B. of Task III of this contract and from the results of tests performed previously under Task IV, Phase I of this contract. Test procedure for the endurance runs will be the same as those specified for the qualifying tests in paragraph B. of Task III except for the total running time of 250 hours, and the bearing material shall be M50 for each oil.

Data Requirements for Task II and Task III

The Contractor shall submit to the NASA Project Manager, photographs of the test cavity showing the test seals and test bearing documenting the extent and nature of the lubricant coking

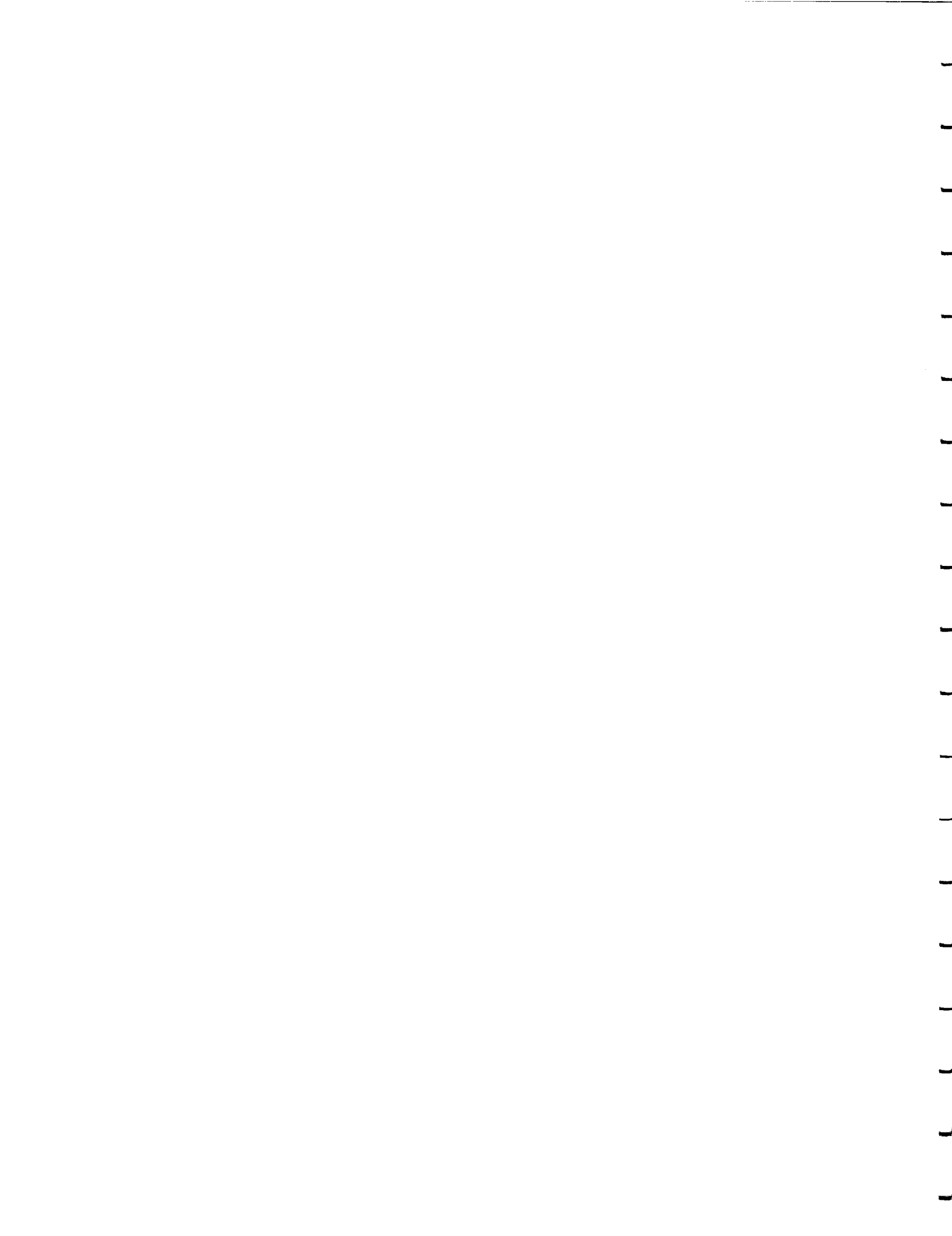
AL68T046

and the visible wear of the test components from each test run disassembly. Samples of system deposits shall be collected. Portions of those samples shall be analyzed and other portions shall be delivered, properly identified, to the NASA Project Manager, at his request. Sump oil samples shall be collected after each screening test run and after each 5-10 hour run during qualifying and endurance testing. Selected samples shall be analyzed as agreed with the NASA Project Manager."



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APPENDIX II  
TEST DATA SUMMARY



## APPENDIX II

TEST BEARING # 267101OIL USED MOBIL JET IIDATE 11-2-67

RUNNING TIME, HOURS	0.7	0.5	1.7	2.2	2.7	2.9			
SPEED, RPM	14	14	14	14	14	14			
MOTOR POWER, VOLT X AMPS									
AIR MANIFOLD PRESS. (PSI)	106	106	107	106	106				
BEARING CAVITY PRESS. (PSI)	6	6	6	6	6				
SEAL CAVITY PRESS. (PSI)	110	111	110	111	111				
HOT AIR FLOW (SCFM)	35	44	42	42	50				
TEST OIL FLOW (GPM)	1.2	1	1	1	0.9				
TOTAL SEAL LEAKAGE (SCFM)	14.4	14.4	13.5	16.4	20.0				
TEST BEARING OUTER RING (OF)	575	540	545	540	540				
TEST BEARING INNER RING (OF)	—	—	—	—	—				
ROLLER BEARING OUTER RING (OF)	450	490	500	500	570				
OIL SEAL HOUSING (OF)	490	505	515	475	470				
AIR SEAL HOUSING (OF)	700	790	815	780	790				
TEST BEARING HOUSING (OF)	500	545	540	535	580				
ROLLER BEARING HOUSING (OF)	530	550	555	540	560				
AIR SEAL BELLOWS (OF)	—	—	—	—	—				
HOT AIR IN MANIFOLD (OF)	1140	1195	1200	1200	1205				
OIL INLET (OF)	435	450	455	445	460				
OIL OUTLET (OF)	450	—	430	425	445				

OIL SEAL LIFT OFF:

OIL BLOWN OUT OF VENT

THE MAJORITY OF THE TOTAL SEAL LEAKAGE WAS ACROSS THE AIR SEAL.

THE OXYGEN CONTENT IN THE TEST BEARING CHAMBER WAS .023-.030%.

TEST BEARING # 267102OIL USED MOBIL JET IIDATE 11-16-67

RUNNING TIME, HOURS	START	0.7	0.8	0.8	1.0				
SPEED, RPM		14	14						
MOTOR POWER, VOLT X AMPS									
AIR MANIFOLD PRESS. (PSI)	106	106	106		106				
BEARING CAVITY PRESS. (PSI)	6	6	6		20-25				
SEAL CAVITY PRESS. (PSI)	111	111	111		111				
HOT AIR FLOW (SCFM)	-	-	-		-				
TEST OIL FLOW (GPM)	1.75	1.5	1.0		1.75				
TOTAL SEAL LEAKAGE (SCFM)									
TEST BEARING OUTER RING (OF)	390	560	740 <sup>+</sup>		550	550			
TEST BEARING INNER RING (OF)	380	550	740 <sup>+</sup>		540	540			
ROLLER BEARING OUTER RING (OF)	410	505	505		-	-			
OIL SEAL HOUSING (OF)	370	600	600		-	-			
AIR SEAL HOUSING (OF)	615	860	860		-	-			
TEST BEARING HOUSING (OF)	555	620	620		-	-			
ROLLER BEARING HOUSING (OF)	505	550	550		-	-			
AIR SEAL BELLAWS (OF)	-	-	-		-	-			
HOT AIR IN MANIFOLD (OF)	760	1080	1010		-	-			
OIL INLET (OF)	-	-	-		-	-			
OIL OUTLET (OF)	360	-	-		-	-			

TEST BEARING TEMPERATURE EXCURSION

## APPENDIX II

TEST BEARING # 267103OIL USED MOBIL JET IIDATE 12-19-67

RUNNING TIME, HOURS	0.3	1.0	1.4	1.5					
SPEED, RPM	4	12	14	14					
MOTOR POWER, VOLT X AMPS									
AIR MANIFOLD PRESS. (PSI)	106	106	106	106					
BEARING CAVITY PRESS. (PSI)	6	6	6	6					
SEAL CAVITY PRESS. (PSI)	111	111	111	111					
HOT AIR FLOW (SCFM)	—	—	40	—					
TEST OIL FLOW (GPM)	1.5	0.8	1	1					
TOTAL SEAL LEAKAGE (SCFM)	4.6	—	—	—					
TEST BEARING OUTER RING (°F)	490	530	590	600					
TEST BEARING INNER RING (°F)	510	590	610	650					
ROLLER BEARING OUTER RING (°F)	450	505	540	540					
OIL SEAL HOUSING (°F)	390	630	650	645					
AIR SEAL HOUSING (°F)	580	865	765	765					
TEST BEARING HOUSING (°F)	595	580	505	600					
ROLLER BEARING HOUSING (°F)	490	520	600	525					
AIR SEAL BELLONS (°F)	—	—	—	—					
HOT AIR IN MANIFOLD (°F)	665	970	850	840					
OIL INLET (°F)	—	—	500	—					
OIL OUTLET (°F)	—	—	425	—					

THE OXYGEN CONTENT IN THE TEST BEARING CHAMBER WAS .036- .05%

TEST BEARING-# 267104  
OIL USED MOBIL XRM 154D

DATE 1-16-68

RUNNING TIME, HOURS	START	1.2		1.2	2.3				
SPEED, RPM	2	14		1	14				
MOTOR POWER, VOLT X AMPS	-								
AIR MANIFOLD PRESS. (PSI)	106	106		106	106				
BEARING CAVITY PRESS. (PSI)	6	6		6	6				
SEAL CAVITY PRESS. (PSI)	111	111		111	111				
HOT AIR FLOW (SCFM)									
TEST OIL FLOW (GPM)	1.5	1.5		1.0	0.7				
TOTAL SEAL LEAKAGE (SCFM)	2-3								
TEST BEARING OUTER RING (°F)	400	465	TEMPERATURE EXCURSION	400	500				
TEST BEARING INNER RING (°F)	420	505		420	510				
ROLLER BEARING OUTER RING (°F)	460	490		415	520				
OIL SEAL HOUSING (°F)	400	595		460	615				
AIR SEAL HOUSING (°F)	590	910		600	870				
TEST BEARING HOUSING (°F)	565	670		460	630				
ROLLER BEARING HOUSING (°F)	480	455		410	485				
AIR SEAL BELLOWS (°F)	-	-		-	-				
HOT AIR IN MANIFOLD (°F)	800	1090		785	1095				
OIL INLET (°F)	-	-		400	440				
OIL OUTLET (°F)	-	-		-	-				

REPLACED SLIP RING

THE OXYGEN CONTENT IN THE TEST BEARING CHAMBER WAS  $\approx 1\%$

## APPENDIX II

TEST BEARING # 267106  
 OIL USED BLENDED MOBIL XRM 109F + 10.06 KENDAX 0839 DATE 2-20-68

RUNNING TIME, HOURS	0.9	1.5	2.3	3.0	3.9		4.9	5.3	6.4	7.4	8.0	
SPEED, RPM	14	14	14	14	14		14	14	14	14	14	
MOTOR POWER, VOLT X AMPS												
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106		106	106	106	106	106	
BEARING CAVITY PRESS. (PSI)	6.5	6.5	6.5	6.5	6.5		6.5	6-25	6-8	6-8		
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111		111	111	111	111	111	
HOT AIR FLOW (SCFM)	48	33	34	34	34		49	43	43	48	—	
TEST OIL FLOW (GPM)	1.25	1.25	1.25	1.5	1.5		1.5	—	1.25	1.25	1.25	
TOTAL SEAL LEAKAGE (SCFM)				1.6	1.6		1.8	+11.4		2.4	2.2	
TEST BEARING OUTER RING (OF)	618	590	580	580	575		690	725	680	695	700	
TEST BEARING INNER RING (OF)	622	590	580	575	575		690	695	680	680	700	
ROLLER BEARING OUTER RING (OF)	565	500	470	465	440		580	550	530	540	540	Q
OIL SEAL HOUSING (OF)	802	777	745	744	727		852	700	685	795	800	U
AIR SEAL HOUSING (OF)	982	970	935	927	920		1020	940	935	970	980	U
TEST BEARING HOUSING (OF)	605	523	485	467	460		737	675	657	665	670	U
ROLLER BEARING HOUSING (OF)	525	460	435	415	410		580	575	560	550	560	U
AIR SEAL BELLOW (OF)	930	925	885	880	870		955	810	815	870	886	U
HOT AIR IN MANIFOLD (OF)	810	—	—	—	—		—	—	—	—	—	
OIL INLET (OF)	470	430	420	430	430		520	—	490	500	—	
OIL OUTLET (OF)	—	—	—	—	—		—	—	—	—	—	

↑ MOMENTARY OIL SEAL  
LIFT OFF

THE MAJORITY OF THE TOTAL SEAL LEAKAGE WAS ACROSS THE AIR SEAL  
 THE OXYGEN CONTENT IN THE TEST BEARING CHAMBER WAS 0.041-0.078%

## APPENDIX II

TEST BEARING # 267108  
 OIL USED MOBIL XRM154D

DATE 4-9-68

RUNNING TIME, HOURS	1.0	1.15	1.3	1.75	2.0	2.45	3.45	4.45	4.95	5.2	
SPEED, RPM	14	14		14		14	14	14	14	14	
MOTOR POWER, VOLT X AMPS											
AIR MANIFOLD PRESS. (PSI)	106	106		106		106	106	106	106	106	
BEARING CAVITY PRESS. (PSI)	6	6		6		6	6	6	6	23	
SEAL CAVITY PRESS. (PSI)	111	111		111		111	111	111	111	111	
HOT AIR FLOW (SCFM)	-	50		50		50	50	50	50	50	
TEST OIL FLOW (GPM)	2.0	2.0		2.0		2.0	2.0	2.0	2.0	1.5	
TOTAL SEAL LEAKAGE (SCFM)	-	-		-		1.7	1.7	1.4	4.4	-	
TEST BEARING OUTER RING (OF)	630	640		650		630	640	640	645	650	
TEST BEARING INNER RING (OF)	630	620		610		610	620	625	630	640	
ROLLER BEARING OUTER RING (OF)	580	580		505		500	500	490	490	500	
OIL SEAL HOUSING (OF)	520	685		720		725	720	755	715	550	
AIR SEAL HOUSING (OF)	890	930		970		975	987	990	985	940	
TEST BEARING HOUSING (OF)	560	555		540		515	505	515	515	515	
ROLLER BEARING HOUSING (OF)	470	490		480		460	440	455	450	450	
AIR SEAL BELLONS (OF)	830	860		925		920	935	940	920	915	
HOT AIR IN MANIFOLD (OF)	-	-		-		-	-	-	-	-	
OIL INLET (OF)	-	480		490		490	495	480	485	-	
OIL OUTLET (OF)	-	-		-		-	-	-	-	-	

↑ SHEAR PINS BROKE

THE MAJORITY OF THE TOTAL SEAL LEAKAGE WAS ACROSS THE OIL SEAL FOR THE FIRST 2 HRS. AND THEN SPLITTING EQUALLY FOR THE FINAL HOUR. THE OXYGEN CONTENT IN THE TEST BEARING CHAMBER WAS 0.009 - 0.02 %